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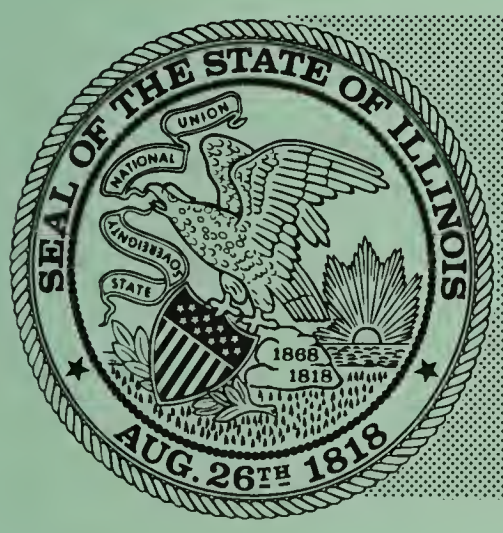
TRANSACTIONS of the ILLINOIS STATE ACADEMY OF SCIENCE

Volume 98, Number 1&2 2005



ILLINOIS STATE ACADEMY OF SCIENCE
Founded 1907

Affiliated with the
ILLINOIS STATE MUSEUM, Springfield

ISSN 0019-2252
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Errata

Please note that the cover for Issue #3&4 of Transactions volume 97 (2004) incorrectly shows a 2005 date. Also, the article by Sietman, et al. was listed it the Table of Contents as beginning on p. 234 when it actually began on p. 235. You may wish to correct these error on the front and back covers of your personal copy.

Issue #3&4 of Transactions volume 97 (2004) also had incorrect error symbols printed in the manuscripts by Bluett et al. and by Sietman et al. The ≥ symbols were transposed and erroneously appeared as ≤ symbols. These were not the errors of the authors, but rather of the electronic printing process. Thus the pages with the incorrect symbols are reprinted in this issue using the page numbers from their original issue for ease in substituting these correct pages in your previous journal copy.

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Reprinted are pages 235-238.

The reprinted pages follow and this issue thus begins subsequently, with the article by McDonnell et al. on page 1.

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Transactions of the Illinois State Academy of Science
(2004), Volume 97, #3&4, pp. 209-217

received 5/25/04
accepted 10/4/04

Status of the River Otter (*Lontra canadensis*) in Illinois, 1998–2004

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ABSTRACT

The Illinois river otter (*Lontra canadensis*) recovery plan recommends de–listing this species from its state threatened status when it is widespread and secure [e.g., stable to increasing populations of reproducing individuals occur in ≥5 of 7 landscape management units (LMUs)]. Sign surveys, surveys of licensed trappers, and element occurrence reports confirmed a statewide distribution of river otters during 1998–2004. Necropsies, sightings of family groups, and recoveries of unmarked individuals from the Illinois, Kaskaskia, and Wabash LMUs confirmed reproduction. Modeling predicted 346 otters released in the Illinois, Kaskaskia, and Wabash LMUs during 1994–1997 increased to 1,830 in 2001 and would reach 4,610 in 2005. We conclude that criteria for de–listing the river otter have been satisfied. We recommend modeling and surveys of licensed trappers for monitoring the future status of river otters in Illinois.

INTRODUCTION

During 1999, the river otter's (*Lontra canadensis*) status in Illinois was upgraded from state endangered to state threatened (Title 17, Illinois Administrative Code, Chapter I, Section 1010). This action was supported by growing numbers of reports from the northwestern, west–central, and southern parts of the state as well as the successful translocation of 346 wild river otters from Louisiana to the Illinois, Kaskaskia, and Wabash river basins (Bluett et al. 1999). We review recent data from field surveys, element occurrence records, questionnaires sent to trappers, necropsies, and a population model to determine whether criteria established for de–listing the river otter have been satisfied.

METHODS

Sign Surveys

Sign surveys are conducted at a stratified random sample of Basin Survey Sites established by the Illinois Environmental Protection Agency and Illinois Department of Natu-

ral Resources (IDNR) to monitor surface water quality, diversity and abundance of fishes, and other indicators of the biotic integrity of riverine systems. Trained IDNR biologists visit designated sites once during 1 Feb through 31 Mar in the southern furbearer zone (i.e., south of U.S. Route 36) and 15 Feb through 15 Apr in the northern zone. Using hip chains to determine distances, they travel ≤300 m upstream and downstream from survey starting points, usually road bridges, and search both shorelines for tracks, scats, and other signs of the presence of river otter, beaver (*Castor canadensis*), and mink (*Mustela vison*) (i.e., a total of 1200 m of shoreline unless the presence of all 3 species is documented in a shorter distance). Data collected by staff include the presence of target species, types of evidence encountered, and percentage of shoreline with conditions deemed suitable to detect an animal's presence.

Questionnaires

Each spring, IDNR mails questionnaires to a stratified random sample of licensed fur trappers to monitor harvest levels and efforts, assess attitudes and opinions, and collect other information pertinent to management programs. Survey instruments distributed after trapping seasons that occurred in 1999–2000 through 2002–2003 asked trappers if they had observed river otters or their sign during the past season (Miller et al. 2002*a*, 2002*b*, 2003, 2004).

Element Occurrence Records (EORs)

Beginning in 1994, IDNR's annual Digest of Hunting and Trapping Regulations solicited reports of river otter observations. Reports from hunters, fishermen, and other members of the public were screened by a follow-up phone call or letter to evaluate their legitimacy and determine precise locations of sightings; those deemed reliable were added to IDNR's Biological Conservation Database. EORs submitted by IDNR staff were another important source of data.

Evidence of Reproduction

Staff from the Cooperative Wildlife Research Laboratory at Southern Illinois University (CWRL) necropsied river otters recovered by IDNR. They assigned ages by appearance of dentition and body size (juveniles) or counts of cementum annuli (specimens >1 year of age; Stephenson 1977) and noted the presence of embryos, placental scars, and traits of lactation (Woolf and Nielsen 2001). EORs provided evidence of reproduction if they reported groups of otters comprised of both adults and juveniles. Recovery of unmarked otters from the Illinois, Wabash, and Kaskaskia river basins also indicated reproductive activity because few if any otters existed in these areas before marked individuals were released during 1994–1997 (Bluett et al. 1999).

Population Model

Using a deterministic population model developed by Hamilton (1998), Woolf and Nielsen (2001) estimated the abundance of river otters inhabiting the Illinois, Kaskaskia, and Wabash river basins during 2001 and 2005. Model inputs included natality and survival estimates from Missouri (Hamilton 1998), and numbers of otters released by IDNR from 1994–1997. Specific input data were presented in Woolf and Nielsen's (2001) unpublished report to IDNR.

RESULTS

Distribution

IDNR biologists conducted Sign Surveys at 41–75 sites annually from 1999–2004 (Table 1). During this period, observations of river otters or their sign originated from 45 sites (Fig. 1) located in all 7 landscape management units (LMUs) and 20 of 21 population management units (PMUs). Otters were detected during multiple (range 2–6) years at most (76%) of the 45 sites.

Numbers of licensed trappers who responded to questionnaires varied from 551–688 per year. Widespread and numerous observations of river otters or their sign were reported during 2002–2003 (118 reports from 56 counties), 2001–2002 (150 reports from 61 counties), 2000–2001 (118 reports from 56 counties), and 1999–2000 (96 reports from 51 counties). Combined reports for 1999–2000 through 2002–2003 originated from 81 counties located in all LMUs and PMUs.

IDNR processed 805 EORs from 1994 through 2003 (Table 2). Those documenting occurrences from 1998 through 2003 (n = 449) originated from 84 counties located in all LMUs and PMUs.

During 1998 through 2004, 9 of 102 counties (DeWitt, Douglas, Edgar, Hamilton, Macoupin, Monroe, Piatt, Putnam, and Stark) lacked records of river otters when data from all sources (i.e., EORs, sign surveys, and trapper reports) were combined. Occurrences were documented by >1 source of data in most (n = 83) counties.

Reproduction

Seventeen of 101 otters assigned ages by CWRL were juveniles. Five females contained embryos, 9 had placental scars, and 22 were lactating. We documented recoveries of 42 untagged river otters and observations of 14 family groups in the Illinois, Wabash, and Kaskaskia LMUs.

Population estimate in release areas

Modeling provided an estimate of 1,830 otters in the Illinois, Kaskaskia, and Wabash LMUs during 2001. The projected estimate increased to 4,610 in 2005.

DISCUSSION

Illinois' recovery plan (Bluett et al. 1995) recommends de–listing the river otter when it is widespread and secure (i.e., stable to increasing populations of reproducing individuals occur in ≥5 of 7 LMUs *or* in 4 LMUs if, in addition, their presence is documented in ≥60% of PMUs). Multiple, independent sources of information indicate criteria for de–listing this species have been satisfied.

Quantitative methods for determining the density of river otters (i.e., mark–recapture studies) are impractical for large spatial scales (Melquist and Hornocker 1979) because of high costs, low recovery rates, strict statistical assumptions, and sampling protocols that are difficult to execute, especially in areas dominated by small, privately held tracts. Alternatives include life table analyses, sighting reports, sign surveys, population models,

and surveys of trappers or agency biologists (Macdonald 1990, Woolf et al. 1997, Melquist et al. 2003). Many of these techniques are affordable but tend to be biased and insensitive to small or moderate changes in densities of wildlife populations (Clark and Andrews 1979). Therefore, experts recommend using ≥2 methods and relying on concordance among results as reasonable assurance they are detecting changes in relative abundance despite their respective limitations (Woolf et al. 1997, Melquist et al. 2003).

Sign Surveys proved useful for monitoring distribution at the LMU and PMU scales. As in Missouri (Gallagher 1999), this method appeared to be a poor indicator of relative abundance. For example, otters were detected at fewer sites in the Illinois, Kaskaskia and Wabash LMUs during 2003 (22.7%) than 2000 (28.9%) yet modeling indicated the population nearly doubled during this 3–year period.

EORs and trapper surveys provided similar information about distribution at the LMU, PMU, and county scales. Without a means of comparing known densities to frequencies of reports, we are unable to evaluate trapper surveys and EORs as indices of abundance beyond noting that both appeared capable of detecting large (e.g., >7–fold increase predicted by modeling for the Illinois, Kaskaskia, and Wabash LMUs) changes during the past decade.

Modeling the statewide abundance of otters is problematic because an estimate of the initial population is required. Numbers of otters released by IDNR from 1994–1997 suffice for 4 LMUs (we include the Fox/DesPlaines/Kankakee LMU, which, based on the timing and number of reports, was colonized by populations originating from releases in the Illinois river basin). We recommend a conservative approach to estimating initial populations in remaining LMUs.

Anderson (1982) estimated <100 otters inhabited the Rock/Mississippi North and Shawnee LMUs during the late 1970s. Aided by immigration from Iowa and Wisconsin, the Rock/Mississippi North population increased and expanded its range by the early 1990s (Anderson 1995). Similar trends in distribution and relative abundance appeared to occur in the Shawnee LMU (Anderson 1995). Allowing for immigration, we believe an initial population estimate of 100 otters is conservative but reasonable for modeling abundance in these 2 LMUs since 1980.

Resource agencies released 1,107 river otters in Missouri and Iowa from 1982–1992 (Raesly 2001). Colonization of Illinois' Middle Mississippi River Tributaries LMU was evident by the early 1990s (Anderson 1995). Assuming ≤5% of otters occupying a LMU are observed and reported to IDNR during a given year, we recommend an initial population estimate of 80 individuals during 1991 (i.e., reports of 4 live otters originated from the Middle Mississippi River Tributaries LMU in 1991). Initial population estimates for western and southern Illinois should be re-evaluated if studies determine densities of river otters for these or similar areas. For example, information about densities and available habitat could be used to derive a population estimate and compare it to results of modeling.

Recognizing that management goals, technologies, and availability of adequate data would probably vary over time, Woolf et al. (1997) recommended a flexible approach to

Transactions of the Illinois State Academy of Science
(2004), Volume 97, #3&4, pp. 235-254

received 6/29/04
accepted 11/20/04

Native Freshwater Mussels (Bivalvia: Unionidae) and Infestation by Zebra Mussels at the Lost Mound Unit of the Upper Mississippi River National Wildlife and Fish Refuge

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ABSTRACT

We characterized the unionid community and extent of zebra mussel infestation along a 21 km reach of the upper Mississippi River known as the Lost Mound Unit of the Upper Mississippi River National Wildlife and Fish Refuge, formerly the Savanna Army Depot. Unionids were present at 81% of the 79 sites sampled totaling 2,440 individuals of 26 species. Catch per unit effort (CPUE) averaged 119.7 ± 107.0 SD unionids/hour (range = 0 to 402.0). Unionids were relatively abundant (CPUE ≥100 unionids/hour) at 34.2% of the sample sites, and of these sites, 66.7% had ≥10 live species. Young were found for up to 77% of the species including the federally endangered *Lampsilis higginsii*. Relative abundance of *L. higginsii* ranged from 0.9 to 2.6% of the community at the four sites it was found alive, which is well within the criteria established for areas of essential habitat. Frequency of unionids infested by at least one zebra mussel (*Dreissena polymorpha*) was 9.1%, with an average of 0.4 ± 1.8 SD zebra mussels/unionid. Species richness in the Pool 12 unionid sanctuary was similar to that observed during studies in 1987 and 1990, prior to the zebra mussel invasion.

INTRODUCTION

The Lost Mound Unit of the Upper Mississippi River National Wildlife and Fish Refuge (Lost Mound Unit), formerly the Savanna Army Depot, is a >3,800 ha tract of bottomland hardwood forest and upland sand prairie-sand savanna bordering the Mississippi River in extreme northwest Illinois, Jo Daviess and Carroll counties. The riverine portion of the refuge consists of an extensive network of backwater lakes and sloughs and several channel border islands. Limited sampling in the area has revealed a potentially diverse

unionid community, including the federally endangered *Lampsilis higginsii* and several Illinois and Iowa listed species (Cawley 1990). No comprehensive study of the area has been done. A portion of the refuge above Lock and Dam 12 was designated as a unionid sanctuary (IDNR 2000) prior to the arrival and spread of the exotic zebra mussel (*Dreissena polymorpha*) (Tucker et al. 1993, Cope et al. 1997), which has devastated many North American mussel stocks (Schloesser et al. 1996).

The objectives of this study were to determine distribution, abundance, and species composition of unionids in the Lost Mound Unit of the upper Mississippi River, to measure extent of zebra mussel infestation on unionids, and to determine effects of zebra mussels at the unionid sanctuary.

MATERIALS AND METHODS

We sampled 79 sites in the upper Mississippi River and its backwaters between River Miles 544.5 and 558.4 from 11 to 16 September 2001 (Figure 1). Fourteen sample sites were within the unionid sanctuary above Lock and Dam 12 at Bellevue, Iowa. We sampled the majority of sites while diving with surface supplied air, but some areas were shallow enough to wade on hands and knees. At each site we did a timed search to measure unionid abundance as catch per unit effort (CPUE) and to estimate species richness (Strayer and Smith 2003). We searched for unionids by moving hands in a sweeping motion on the substrate surface and by probing the substrate with fingers. We sampled sites for 3 to 40 min (mean = 15.5 min ± 8.1 SD). We usually abandoned sites in ≤10 min if we found ≤5 unionids, thus allowing greater coverage of the study area. We concentrated samples along channel borders, side channels, and the head and toe of islands, and we avoided sampling the navigation channel, which is periodically dredged. We also searched the shoreline for shells at several sites, but did not include these data in the total time sampled. We recorded Universal Transverse Mercator (UTM) coordinates (NAD83, Zone 15) for each site with a Trimble Pathfinder® Global Positioning System.

All live and most dead unionids encountered were placed in a mesh bag until the end of the search period, and except for those kept as vouchers, were returned to the river following processing. Dead unionids with tissue present, or shiny nacre and intact periostracum were categorized as recently dead, and those with chalky nacre and worn periostracum, other than normal umbonal erosion, were categorized as weathered dead. We recorded length (anterior-posterior axis) to the nearest millimeter for all unionids except for some individuals of *Amblema plicata*. Zebra mussels attached to individual unionids were removed and counted. We did not estimate zebra mussel abundance on other substrates at sample sites. We also recorded aquatic snails, fingernail clams (Sphaeriidae), and Asian clams (*Corbicula fluminea*) when encountered. Nomenclature follows Turgeon et al. (1998), and voucher specimens were deposited in the Illinois Natural History Survey Mollusk Collection, Champaign.

RESULTS

Unionid Community Characterization

We collected 2,440 individuals representing 26 species in 20.4 hr of sampling (Table 1). Included were six individuals of *Lampsilis higginsii*, which were collected alive at four

sites, the Illinois and Iowa Threatened *Ellipsaria lineolata* and Illinois Threatened *Ligumia recta*, which were collected at three and nine sites, respectively, and the Iowa Endangered *Pleurobema sintoxia* and Iowa Threatened *Strophitus undulatus*, which were collected at one site each. We found weathered shells of an additional eight species, and three species represented by museum specimens were not found during this study (Table 1).

Amblema plicata was the most abundant and widespread species, comprising 35.1% of all individuals and occupying 64.6% of sites. Other relatively abundant species included *Obliquaria reflexa* (17.9%), *Fusconaia flava* (9.2%), *Lampsilis cardium* (6.1%), *Quadrula quadrula* (6.5%), *Pyganodon grandis* (6.0%), and *Obovaria olivaria* (6.0%) (Table 1). These species also were some of the most broadly distributed species in the study area along with *Leptodea fragilis*, *Lasmigona complanata*, *Potamilus ohiensis*, *Quadrula pustulosa*, *Q. nodulata*, *Truncilla donaciformis*, and *T. truncata* (Table 2). Length frequency distributions indicated that up to 77% of the 26 species we found alive had recent recruits to their populations, which we define as Amblemines ≤40mm, Anodontines and Lampsilines ≤60mm, and *Toxolasma* and *Truncilla* ≤10mm (Table 3). Included among these were three small (43, 50, and 62mm) *L. higginsii* that we estimated at three (one individual) and four (two individuals) years of age based on external annuli.

We found at least one live unionid at 81.0% of the sample sites (Table 2), and CPUE averaged 119.7 ± 107.0 SD unionids/hour (range = 0 to 402.0). Unionids were absent or sparse (≤25 unionids/hour) at 40.5% of the sites sampled. There were 27 sites (34.2%) with CPUE ≥100 unionids/hour, 14 sites (17.7%) with CPUE ≥200 unionids/hour, and six sites (7.6%) with CPUE ≥300 unionids/hour. Of the sites with CPUE ≥100 unionids/hour, 66.7% had ≥10 live species.

Unionid Sanctuary

In 4 hr of sampling, we collected 664 individuals of 20 species, including one live *Lampsilis higginsii*. *Amblema plicata* (36.6%), *Obliquaria reflexa* (23.5%), and *Quadrula quadrula* (13.1%) were the most abundant species in the sanctuary, and *A. plicata*, *Megalonaias nervosa*, *Q. quadrula*, *Leptodea fragilis*, and *O. reflexa* seemed more abundant in the sanctuary than in the downstream portion of the study area. We found live unionids at all but one sample site (Table 2), and CPUE averaged 166.8 ± 116.6 SD unionids/hour (range = 0 to 351.0). Of the 14 sites sampled in the sanctuary, eight had CPUE ≥100 unionids/hour, five had CPUE ≥200 unionids/hour, and one had CPUE ≥300 unionids/hour. Five sites had ≥10 species. Species richness of live unionids and relative abundance of most species appeared similar in this study to samples collected in 1987 and 1990, prior to the establishment of zebra mussels (Table 4).

Zebra Mussels

Infestation of unionids by zebra mussels was rare throughout most of the study area (Table 2). Zebra mussels were observed infesting unionids at only 35.9% of the sites where live unionids were collected. Overall frequency of unionids infested by at least one zebra mussel was 9.1%, with an average of 0.4 ± 1.8 SD zebra mussels/unionid. Frequency of zebra mussel infestation was 30.0% (average zebra mussels/unionid = 1.2 ± 3.4 SD; range = 0 to 33) in the unionid sanctuary compared to 1.3% (average zebra mus-

sels/unionid = 0.02 ± 0.2 SD; range = 0 to 7) in the remainder of the study area, and 89.6% of all zebra mussel infested unionids were from the sanctuary.

DISCUSSION

Our estimate of species richness at the Lost Mound Unit is similar to other recent upper Mississippi River studies which rarely find >30 extant species within a given river reach (Havlik and Stansberry 1978, Theil 1981, Havlik 1983, Miller 1988, Holland-Bartels 1990, Hornbach et al.1992, Hart et al. 2002). The presence of 11 species that were found only as weathered shells or museum specimens suggest that up to 30% of the historic unionid community might have been lost from this river reach, although it is unlikely that we found all extant species in the area. Several of these species are currently rare in the upper Mississippi River (Havlik and Sauer 2000), some of which were apparently historically rare as well (e.g., *Elliptio crassidens*, *Lasmigona costata*, and *Plethobasus cyphyus*) (van der Schalie and van der Schalie 1950). The decline in unionid species richness from this river reach almost certainly occurred prior to the arrival of zebra mussels, and is likely attributable to the degradation of natural riverine habitat (Scarpino 1985, Afinson 2003).

Species richness and relative abundance of unionids in the sanctuary appeared similar in this study compared to samples collected in 1987 and 1990, prior to the establishment of zebra mussels (Table 4), and any variation in relative abundance of species among years could be due to site selection and sampling methods (E. Cawley, Loras College, Dubuque, Iowa, pers. comm.). Cawley (1990) found the unionid community below Lock and Dam 12 to be as diverse as within the sanctuary above the dam, with mostly young (<50mm in length) *Lampsilis higginsii* occurring at a relative abundance of 3.3%. This is well above the 0.25% relative abundance criteria used to establish areas of essential habitat for this species (U. S. Fish and Wildlife Service 2004). Cawley (1990) correctly suggested this area be included within the unionid sanctuary. We also found *L. higginsii* to be relatively abundant on the Iowa side of the river at Sites 23 (1.7%) and 26 (2.6%) adjacent to channel border islands along Harrington Slough, and at Site 39 (1.9%) at the head of Bowman Island, all of which were areas with relatively high unionid species richness. These areas should also be considered as essential *L. higginsii* habitat.

Zebra mussels were not abundant in this river reach during our study. The low number of zebra mussels might be related to an extensive zebra mussel die-off that occurred in other reaches of the upper Mississippi River during late summer 2001 (see news article by Nissen 2003), or it might be characteristic of their overall abundance in this area. By comparison, in 1995 Cope et al. (1997) found the density of zebra mussels averaged 8,000/m^2 on colonization samplers at Lock and Dam 12, the second highest density among 18 lock and dam sites sampled in the upper Mississippi River. Abundance of zebra mussel larvae at Lock and Dam 12 was also found to be among the highest in the upper Mississippi River in summer 1998 and 1999 (Stoeckel et al. 2004). This corresponds to Ecological Specialists, Inc., (O'Fallon, Missouri, unpubl. data) finding in 2000 that zebra mussels infested >99% of unionids sampled, encrusting 41% of unionid shells on average, in the reach just below the dam. We noted patches of zebra mussel byssal threads on the shells of live unionids at several sites, as well as areas where unionids were generally free of byssal threads, suggesting zebra mussel infestation was previously variable in the study

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beginning on page 1 with the article by McDonnell et al.

Transactions of the Illinois State Academy of Science
(2005), Volume 98, #1&2, pp. 1-17

received 1/10/05
accepted 6/4/05

Influence of Stem Cutting and Glyphosate Treatment of *Lonicera maackii*, an Exotic and Invasive Species, on Stem Regrowth and Native Species Richness

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ABSTRACT

Lonicera maackii (Rupr.) Herder (Caprifoliaceae), Amur honeysuckle, is an exotic and invasive species in the United States that has quickly overtaken disturbed habitats in the eastern and midwestern United States, as well as in Ontario, Canada. A reduction of light due to its dense canopy, extended growing season compared to native species, and production of numerous basal sprouts allow *L. maackii* to outcompete its native counterparts. Eradication of this species can be difficult and time-consuming. This research was undertaken to identify how *L. maackii* influences species diversity and species re-establishment and to determine an efficient and effective eradication method. A study was designed to determine if *L. maackii* inhibited species diversity, if the removal of *L. maackii* would increase species diversity by reopening the canopy, and if mechanical removal or mechanical removal coupled with glyphosate treatment could be used effectively for its long-term eradication. It was found that *L. maackii* removal increased species diversity, and mechanical removal coupled with the application of glyphosate is an effective and relatively simple method for eradicating *L. maackii*, while mechanical stem removal alone simply delayed its growth.

INTRODUCTION

Lonicera maackii (Rupr.) Herder (Caprifoliaceae), Amur honeysuckle, was introduced into the United States in 1897 from Asia because of its ornamental properties (attractive flowers, fruit, and fragrance) and ability to provide habitat for wildlife [Minnesota Department of Natural Resources (MDNR), 2003; Hutchinson and Vankat, 1997; Luken et al., 1997; Luken and Thieret, 1996]. *L. maackii* is an erect, deciduous shrub that can range anywhere from 2 to 6 m in height when mature. Its invasion into forests and disturbed areas began as it escaped cultivation. *L. maackii* has quickly overtaken disturbed habitats, especially in the last few decades, and has also been known to invade open areas with little vegetation that are not disturbed (Collier and Vankat, 2002; Luken and Thieret, 1996; Trisel and Gorchov, 1994). It is now found in at least 24 states throughout the east-

ern and mid-western U.S. and in Ontario, Canada (Hutchinson and Vankat, 1997; Trisel and Gorchov, 1994).

L. maackii seedlings are likely to establish themselves in forest understories and in open areas with little vegetation (MDNR, 2003; Hutchinson and Vankat, 1997; Luken and Theiret, 1996). Seeds were shown to germinate readily in both light and dark environments (Luken and Goessling, 1995). High germination rates and aggressive plant growth also contribute to the competitiveness of *L. maackii* with native species. In addition, maturing plants were shown to adapt and grow well in areas with different light intensities (Luken, 1988). Growth and reproduction are aggressive and rapid. Initial fruits are produced when the plant becomes woody, within three to five years after seedling establishment (Luken and Thieret, 1996).

The invasiveness of Amur honeysuckle also is a function of its extended growing season, ranging from early March to mid November (Trisel and Gorchov, 1994). Early expansion of *L. maackii* leaves has negative effects on native plants (especially spring ephemerals) giving it a distinct competitive advantage (Hoffman and Kearns, 1997; Trisel and Gorchov, 1994). Leaves of *L. maackii* were found to be photosynthetically active for a significantly longer time than three native species (*Acer saccharum* Marsh., *Asimina triloba* (L.) Dunal. (Pawpaw), and *Lindera benzoin* (L.) Blume.) (Trisel and Gorchov, 1994). Also, leaves are retained on *L. maackii* plants longer (until mid November) than most native plants, due to lack of herbivory and biological control agents (MDNR, 2003). Biological controls are not known for *L. maackii*, and leaf damage recorded at the end of the growing season was shown to be lower for *L. maackii* than for other native, woody species (Batcher and Stiles, 2003; Trisel and Gorchov, 1994). The lack of biological control agents, as shown on a related species, *Lonicera japonica* Thunb. var. japonica, illustrates how important biological agents are in maintaining plant communities (Schierenbeck et al., 1994). Although it has been suggested that bush honeysuckles (including *L. tartarica* L., *L. maackii*, and *L. morrowii* Gray) may produce allelopathic chemicals, it has not been documented (MDNR, 2003).

Both early leaf expansion and extended growing season are two factors that affect species richness by creating a dense canopy, which is negatively associated with native and non-native species richness (Collier and Vankat, 2002; Gould and Gorchov, 2000; Hoffman and Kearns, 1997; Hutchinson and Vankat, 1997). This dense canopy may inhibit native species by depleting soil moisture and nutrients and reducing light availability (Collier and Vankat, 2002; Gould and Gorchov, 2000; Hoffman and Kearns, 1997; Hutchinson and Vankat, 1997). Species richness and abundance and tree seedling abundance were shown to be significantly greater in areas without an Amur honeysuckle canopy cover compared to areas where *L. maackii* had produced a dense canopy (Collier and Vankat, 2002; Hutchinson and Vankat, 1994). Results of a study done showing the effects of canopy cover of *L. maackii* on native annuals illustrated that annual plants, particularly shade intolerant species, declined in the presence of a canopy cover (Gould and Gorchov, 2000). One study demonstrated increased light availability (about 10% of full sun) for plants where *L. maackii* shrubs were removed, compared to approximately 1% of full sun light availability where shrubs remained (Luken et al., 1997). Light availability significantly and positively increased overall plant density; however, increasing light availability for plants may not only encourage native species to grow, but also promote non-

native, invasive species, such as *Allaria petiolata* (Bieb.) Cavara & Grande (garlic mustard) (Luken et al., 1997).

Large quantities of red berries are produced by *L. maackii* (Luken and Thieret, 1996; Ingold and Craycraft, 1983). The main agent of seed dispersal is birds that consume the red berries (Ingold and Craycraft, 1983).

L. maackii abundance has the ability to negatively alter forest structures and native herbaceous populations (Hutchinson and Vankat, 1997). It has also been shown that the longer *L. maackii* shrubs persist in forests, species richness and abundance of tree seedlings decreased (Collier and Vankat, 2002).

The flowers of *L. maackii* are initially white and become yellowish with age and emit an attractive fragrance (MDNR, 2003). Many homeowners desire this plant in their gardens because it is one of the most aesthetically pleasing species among honeysuckles (Bean, 1973). While the shrub is still planted as a decorative landscaping specimen, there are efforts to eradicate it. Eradication can be a difficult and time-consuming process because of its invasive and anti-herbivory qualities. The two most widely documented methods for successful eradication have been burning and glyphosate (RoundUp™) application to either whole shrubs or cut stems (Batcher and Stiles, 2003; MDNR, 2003). However, there is a potential hazard with using burning as an eradication method, especially in residential areas. Another eradication method that has been used with some success is mechanical removal of entire shrubs; however, this method is particularly disruptive to residential landscapes. Therefore, in residential areas, applying glyphosate to a cut stem is a more appropriate method. Any of these methods would take more than a year to completely prevent its re-establishment because the seed bank in the surrounding soil may be quite extensive due to *L. maackii*'s abundant seed production (Batcher and Stiles, 2003). In this study, a practical approach to the removal of *L. maackii* was taken to determine whether the presence of *L. maackii* inhibits diversity, whether the opened canopy would enable the once abundant wildflowers to re-establish themselves, and the efficacy of applying concentrated glyphosate directly to cut stems compared to mechanical stem removal only.

MATERIALS AND METHODS

This study was conducted on a residential area in Charleston (Coles Co.), Illinois (39°28'N, 80°10'W) from mid May to mid July in 2003 and 2004. Three 20 m transects (approximately 5m between transects) were positioned running east and west (Fig. 1). Data from all honeysuckle shrubs within 2m of all transects was recorded. In May 2003, *L. maackii* stems in transects A and B were mechanically removed (either by saw or pruning shears, where appropriate) 10 cm above the soil surface. In addition, all newly cut stems within 2 m of transect A were treated with an 18% solution of glyphosate [n-(phosphonomethyl)glycine] by painting the solution directly onto cut stems. Transect C remained untreated (i.e. no removal, no glyphosate application).

An initial inventory of mature honeysuckle, including number and height of mature shrubs, number of stems per shrub, and stem diameter was determined prior to any removal. An inventory of species diversity and abundance was recorded in alternating 0.5

m^2 quadrats (40 quadrats/transect). After the mechanical removal of honeysuckle stems (May 28, 2003), six weekly inventories (June 6 to July 9, 2003) of each transect were conducted to monitor any re-growth of honeysuckle stems and growth of understory plants. Species inventory was also recorded weekly in the second year (May 26 to July 8, 2004). Stem numbers and lengths of mature *L. maackii* shrubs in transect A (mechanical removal coupled with glyphosate) and transect B (mechanical removal alone) were recorded weekly in both 2003 (May 28 through July 9) and 2004 (May 26 through July 8). Species richness was tested using both univariate analyses of variances (ANOVAs) and Tukey tests with SPSS 13.0 (SPSS, Inc., Chicago, IL). Weekly measurements also were taken of light intensity (μmol/m^2/sec; 13 cm above soil surface) and soil temperature (°C; 5-8 cm below soil surface) at three locations along each transect. Significant differences in light intensities and soil temperatures were also analyzed using ANOVAs with SPSS 13.0. All analyses were conducted with an alpha level of 0.05.

RESULTS

Stem data

The initial inventory of mature, woody honeysuckle shrubs in all three transects was taken in the first week of both years (Table 1). No new shoots sprouted in 2004 on honeysuckle shrubs that had bee treated with glyphosate in 2003. Stem number and stem length also were recorded to determine the extent of re-growth after mechanical removal alone. In the first year, shoots started to emerge after three weeks on cut honeysuckle stems in transect B (no glyphosate). Most of these shoots were buds, so no stem lengths were recorded until week four. The second year of data revealed that stem number did not increase greatly, but stem length increased almost threefold (Fig. 2). Biomass (as determined by average stem number multiplied by average stem length) increased by more than three times of the amount of total re-growth recorded at the end of the first year (432) as compared to indicated biomass in the second year (1469).

Species richness

Species quantity and type were recorded over a span of seven weeks for both years and the total average frequency was calculated to show richness of different species per transect (Table 2). Some species were difficult to identify as seedlings at the beginning of data collection for both years, until the plants grew and became more distinguishable. These small seedlings were recorded in the "miscellaneous seedlings" category until they were able to be identified in subsequent weeks.

In the first year, statistical analyses were conducted to determine density of three species of plants [*Viola pratincola* Greene (violets), *Acer negundo* L. var. negundo (boxelder), *Lonicera maackii*] and species richness. Each species was tested using a univariate analysis of variance. *Lonicera maackii* and *Acer negundo* seedlings and species richness were also analyzed from the second year of data. *Viola pratincola* showed a significant difference in all weeks (all weeks showed a probability value=0.000, df=2, 117, all r^2 values <0.340) for all of the transects, including its initial inventory. Because the difference in abundance of *V. pratincola* between transects was present from the beginning of the study, it was deemed a non-useful indicator of species re-establishment and therefore they were not analyzed in the second year. In contrast, since boxelder and Amur honey-

suckle seedlings were uniformly distributed amongst all transects in the beginning of the study, they were deemed useful indicators of species re-establishment.

In the first year, there were not any significant differences of *Acer negundo* seedlings between transects for all weeks under study (Fig. 3). Week three of the second year was the first week that illustrated any significant differences between transects. Both cut transects, A and B, showed significantly greater abundances of boxelder seedlings compared to transect C ($p=0.003$, $df=2, 117$ and $p=0.036$, $df=2, 117$, respectively). However, in this week there was not a significant difference between transect A and transect B ($p=0.682$, $df=2, 117$). Also, week four of the second year showed seedling abundance to be significantly greater in transect A compared to transect B ($p=0.016$, $df=2, 117$) and transect A compared to transect C ($p=0.000$, $df=2, 117$). However, there was not a significant difference between transect B and the control ($p=0.503$, $df=2, 117$). Seedling abundance was greatest in transect A (glyphosate) compared to the other transects for all weeks in the second year as shown in Figure 3.

The number of *Lonicera maackii* seedlings were not significantly different in the three treatments during any of the test weeks in the first year ($p>0.05$ for all weeks, $df=2, 117$) (Fig. 4). In the second year, however, *L. maackii* seedlings in transect A were significantly greater than seedlings in transect C for all weeks except week two ($p<0.046$ for all weeks that were significantly different, $df=2, 117$) (Fig. 4).

Lonicera maackii seedlings in week four of the second year were analyzed. The number of seedlings in transect A compared to transect B were significantly greater ($p=0.000$, $df=2, 117$). The number of seedlings in transect A compared to the control were also significantly greater ($p=0.000$, $df=2, 117$). The number of seedlings in transect B compared to the control were not significantly different ($p=0.709$, $df=2, 117$).

Before the honeysuckle stems were cut, there were no significant differences in species richness between treatments. On June 25, 2003 (week 5) there was a significant difference between transect A and the control in this week ($p=0.007$, $df=2, 117$) (Fig. 5). However, there were not significant differences between transect A and transect B ($p=0.051$, $df=2, 117$) and transect B and the control ($p=0.754$, $df=2, 117$). Significant differences observed in the first year did not persist throughout all the weeks of this study. Week five of the second year showed there to be significant differences between all transects ($p=0.000$, $df=2, 117$) (Fig. 5). All transects showed significant differences between each other ($p=0.000$, $df=2, 117$, for all combinations). As the canopy returned (in 2004 in transect B), species richness was lower than transect A (Fig. 5).

Environmental data

Soil temperatures for both years were not significantly different between transects when analyzed in SPSS 13.0 in 2003 ($p=0.089$, $df=2, 54$), and in 2004 ($p=0.231$, $df=2, 60$). Light intensities for both years were shown to be significantly different between transects in 2003 ($p=0.007$, $df=2, 54$) and in 2004 ($p=0.000$, $df=2, 60$). Mean values for light intensities and soil temperatures are shown in Table 3.

DISCUSSION

Stem data

The initial inventory of the mature honeysuckle indicates similar plant densities and sizes of the shrubs among the three transects, thus enabling useful comparisons. Results show that *L. maackii* is a dominant species at this location. Cut stems without glyphosate application initiated new shoots within three weeks, illustrating the inefficiency of mechanical stem removal as a singular eradication method. By contrast, no stems were initiated in either the first or second years on plants cut and treated with glyphosate, suggesting that the herbicide killed those individuals.

The significant re-growth of stems in transect B (compared to the total lack of regrowth in transect A) indicates that mechanical stem removal without herbicide treatment does not eradicate *L. maackii*. In fact, overall stem lengths were much greater in the second year for transect B, illustrating that not only is mechanical stem removal without herbicide treatment an unsuccessful eradication method, it actually promotes new shoot growth that would quickly re-establish biomass (Fig. 2). Mean heights of *L. maackii* in the control transect were estimated data, thus explaining a decrease in mean heights of mature honeysuckle shrubs in this transect from 2003 to 2004 (Table 1).

Species richness

The number of *Acer negundo* seedlings was much larger in the first year than the second year. However, in the second year, although there were fewer boxelder seedlings overall, there were significant differences between all three transects (Fig. 3). Evidently, there were more boxelder seedlings in the seedbank in 2003 than 2004. Although boxelder seedlings were not noted to be significantly greater in transect A compared to transects B and C until week 4, Figure 3 shows that transect A (glyphosate) contained the greatest number of boxelder seedlings in all weeks. By week three, there were significantly fewer boxelder seedlings in the control transect than in the two removal transects, suggesting that it is an opportunistic species. This information supports the initial hypothesis that seedling abundance is greater in areas where light availability is increased due to canopy removal. Also, since seedling abundance was shown to be greater in transect A (glyphosate) than transect B for most weeks in the second year of study, it is apparent that mechanical stem removal alone (in transect B) does not increase its species richness in that area.

The number of *L. maackii* seedlings was not significantly different between all three transects in the first year. Amur honeysuckle seedlings were approximately uniformly distributed throughout all transects for the first year of data collection. A dramatic increase in seedling abundance (in both transects A and B) in the second year is illustrated by Figure 4. This increase in seedling abundance further emphasizes that increased light availability by canopy removal (or reduced canopy) positively influences seedling density. In the second year, honeysuckle seedlings were significantly greater in transect A as compared to transects B and C (Fig. 4). Seedlings likely sprouted from the seedbank and were able to survive due to the newly opened canopy that previously inhibited seedling establishment in all transects. Due to unsuccessful eradication techniques, the canopy in transect B had begun re-establishing itself (by the summer of 2004), and there were fewer seedlings in this transect, which may be due to reduced light caused by the returning can-

opy. The significantly greater number of seedlings in transect A indicates that more seedlings are able to grow in the absence of a canopy; however, there were some differences in the understory species between the transects where *L. maackii* was removed and the control in the first year. Data from the second year indicates that there is a significant difference in species richness between all three transects. Figure 5 illustrates that species richness was greater where there was a more open canopy. Transect A showed the greatest species richness, where transect B showed significantly less species richness than transect A (Fig. 5). Species richness in both transects A and B was significantly greater than the species richness in transect C. Our results agree with Collier's and Vankat's (2002) findings that species richness is lower where *L. maackii* develops a dense canopy. This result makes sense given the invasive qualities of *L. maackii.* It is interesting that, in the initial inventory, there were more *L. maackii* seedlings in transect C than in either A or B. However, after *L. maackii* was removed from A and B and the canopy was reopened, honeysuckle seedlings in transects A and B increased slightly (more so in the second year), while at the same time decreased in transect C over the length of the study. Figure 5 suggests that ridding a transect of its honeysuckle canopy leads to a greater species richness, and that mechanical stem removal alone (transect B) does not prohibit regrowth of the canopy, which ultimately leads to a lower species diversity. Also, since species richness was found to be greater in transect A than transects B and C (week five of the second year), and species richness was not found to be significantly different between transect B and the control in this same week, this data further shows evidence of a lower species diversity and richness in areas where Amur honeysuckle was only mechanically removed and its canopy regrowth inhibited an increase of species diversity.

Native species such as *Acer saccharinum* (L.) (silver maple), *Aster lateriflorus* (L.) Brit. (side-flowering aster), and *Impatiens capensis* Meerb. (spotted touch-me-not) were observed in the second year of data but not the first (Table 2). Table 2 also illustrates that *Aster lateriflorus* seedling density was observed to be greater in transect A (glyphosate) than both other transects. The violets increased as well, once the canopy was opened. The mean number of violets increased greatly in both cut transects in 2004. *Geum canadense* Jacq. increased in abundance in transect A in the second year compared to its mean value in the first year. This species was also more abundant in transect A compared to the other transects in the second year.

All non-native species observed the second year were observed in the first year as well (Table 2). However, *Taraxacum officinale* Weber (dandelion) was observed the second year but not in the first. Since dandelions were only noted in transect A (glyphosate), this indicates that non-native plant species are likely to invade in areas where *L. maackii* has been removed. Also, Amur honeysuckle seedlings increased dramatically in transect A in the second year, indicating yet again that non-native species are likely to invade when Amur honeysuckle's canopy is removed.

After analyzing the second year of data, it was found that species richness increased when the canopy was opened and mechanical removal alone was not a successful technique for eradication. Even after cutting and treatment with glyphosate, *L. maackii* likely persists in the seedbank. Removing sprouting seedlings by hand after removing the canopy may be a technique to remove all honeysuckle plants. Although this removal may

need to be done over more than one year, it is probably one of the most successful ways to eradicate *L. maackii* completely in an area.

Environmental data

Results of this study are in accordance with previous studies that illustrated that light intensity was noticeably lower in the control compared to transects A and B in the first and second years (Hutchinson and Vankat, 1997; Luken et al., 1997). This difference indicates that *L. maackii* produces a dense canopy, shading and inhibiting herbaceous plant growth. Light intensity was higher in transect A in the second year, as compared to the other transects. Since the canopy remained opened in the second year, this could be a reason why the light intensity was greater in that transect. Also, since a large amount of regrowth appeared in transect B during the second year, its light intensity would be expected to be lower than transect A.

Soil temperatures were not significantly different between transects in the second year, however. Soil temperatures may have shown no significant differences due to low, herbaceous plants shading the ground in transects A and B.

ACKNOWLEDGMENTS

The authors thank Dr. Janice Coons for access to the site, Dr. Scott Meiners for statistical consultation, Ms. Marijana Peric for assistance in data collection, and Dr. Gordon Tucker for species identification. Funds to support this project were provided in part by the National Science Foundation Research Experience for Undergraduates (NSF-REU) program and a grant from the Undergraduate Research Council of Eastern Illinois University's Honors College.

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Figure 1. Layout of study site. The shaded area rectangle represents the area where the Amur honeysuckle shrubs were cut within two meters of transects A and B.

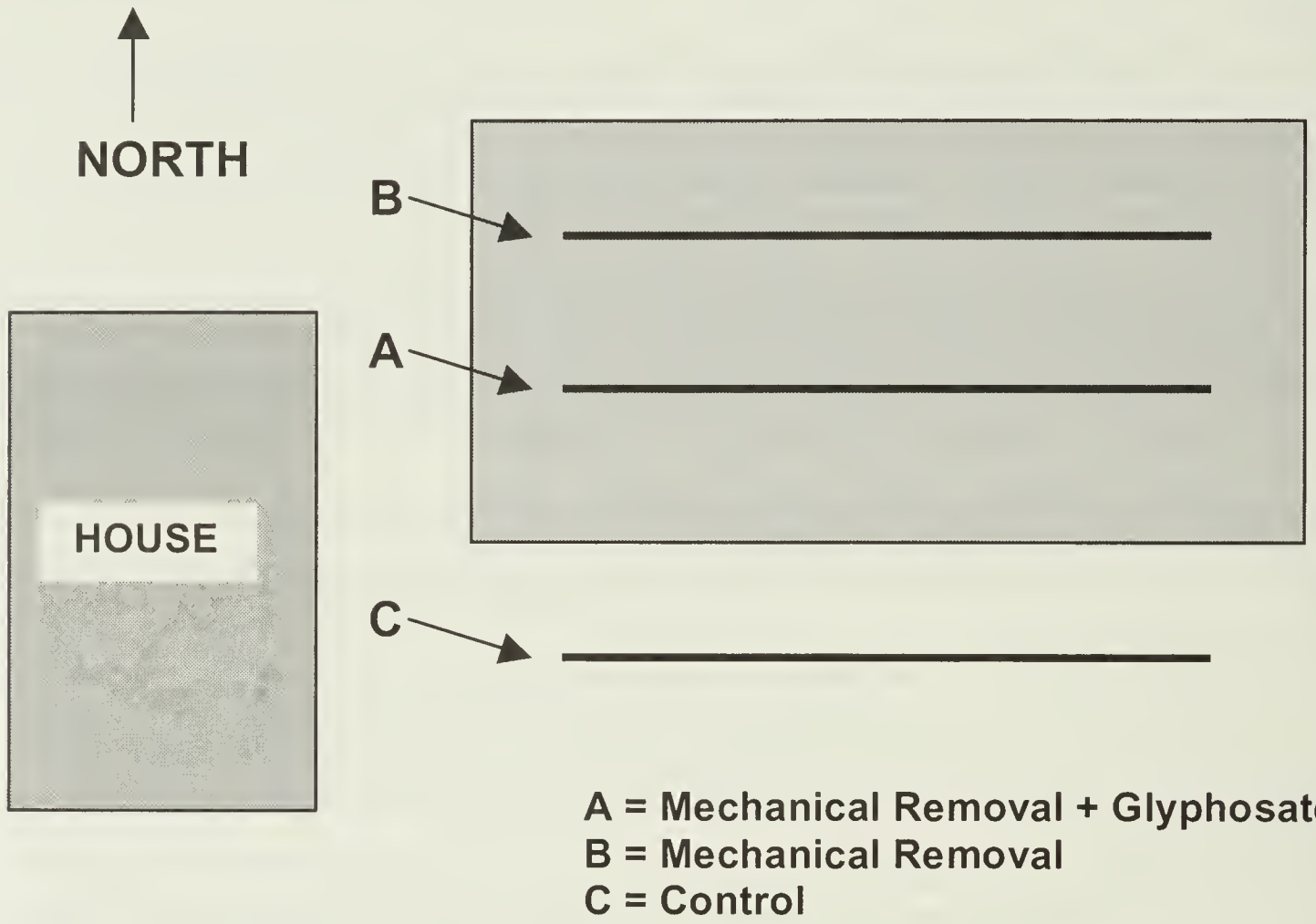


Table 1. Initial inventory of mature *L. maackii* within all three transects from the first and second years of data with standard errors.

	# of shrubs	shrubs/m^2	mean height (m)	mean # stems/shrub	mean stem diameter (mm)
2003					
Glyphosate	34.0	3.4	2.6 ± 0.16	4.4 ± 0.42	22.9 ± 1.40
Cut	23.0	2.3	3.0 ± 0.19	5.0 ± 0.51	38.1 ± 14.4
Control	30.0	3.0	3.0 ± 0.18	3.5 ± 0.37	24.0 ± 1.46
2004					
Glyphosate	0.0	0.0	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00
Cut	20.0	2.0	1.2 ± 0.09	14.4 ± 1.43	4.6 ± 0.26
Control	30.0	3.0	2.7 ± 0.13	3.8 ± 0.049	26.6 ± 2.76

Table 2. Overall mean abundance (plants/m^2) of understory plant species in 2003 and 2004 by transect for all weeks (Mohlenbrock, 2002).

	Glyphosate	Cut	Control
2003			
Native			
Acer negundo	6.2	6.2	4.7
*Brachythecium oxycladon**	1.9	0.4	0.4
Carex jamesii	1.6	1.1	0.1
Geum canadense	1.8	0.2	1.3
Sambucus canadensis	0.0	0.4	0.0
Smilax hispida	0.1	0.0	0.2
Toxicodendron radicans	0.7	0.0	0.5
Viola pratincola	10.9	31.7	0.7
Non-native			
*Ajuga reptans**	0.0	6.4	0.0
Lonicera japonica	0.0	0.1	3.0
Lonicera maackii	1.3	1.3	1.9
Morus alba	0.0	0.0	0.1
Rosa multiflora	0.4	0.1	0.4
*Vinca minor**	0.0	0.0	7.3
Miscellaneous seedlings	16.1	17.2	13.5
Other	0.7	0.5	0.3
2004			
Native			
Acer negundo	28.5	13.0	2.8
Acer saccharinum	5.0	1.8	1.6
Aster lateriflorus	11.0	4.5	0.0
*Brachythecium oxycladon**	5.0	0.5	0.5
Cercis canadensis	0.0	1.2	4.3
Fraxinus americana	0.0	0.5	0.5
Fraxinus lanceolata	62.5	54.5	2.5
Geum canadense	38.3	3.8	9.0
Impatiens capensis	16.3	1.0	0.0
Oxalis stricta	2.0	2.3	0.0
Phytolacca americana	0.3	0.0	0.0
Toxicodendron radicans	14.5	0.0	11.8
Viola pratincola	568.0	825.8	4.5
Non-native			
*Ajuga reptans**	0.0	2.7	0.0
Lonicera japonica	3.0	2.5	3.5
Lonicera maackii	135.3	79.8	49.0
Morus alba	2.5	0.5	2.5
Rosa multiflora	9.8	1.3	4.3
Taraxacum officinale	2.1	0.0	0.0
*Vinca minor**	0.0	0.0	14.8
Miscellaneous seedlings	66.0	28.8	49.5

*Indicates a percentage cover.

Figure 2. Average stem numbers and stem lengths in transect B (mechanical stem removal only) of Amur honeysuckle recorded in the seventh week of data collection in 2003 and 2004.

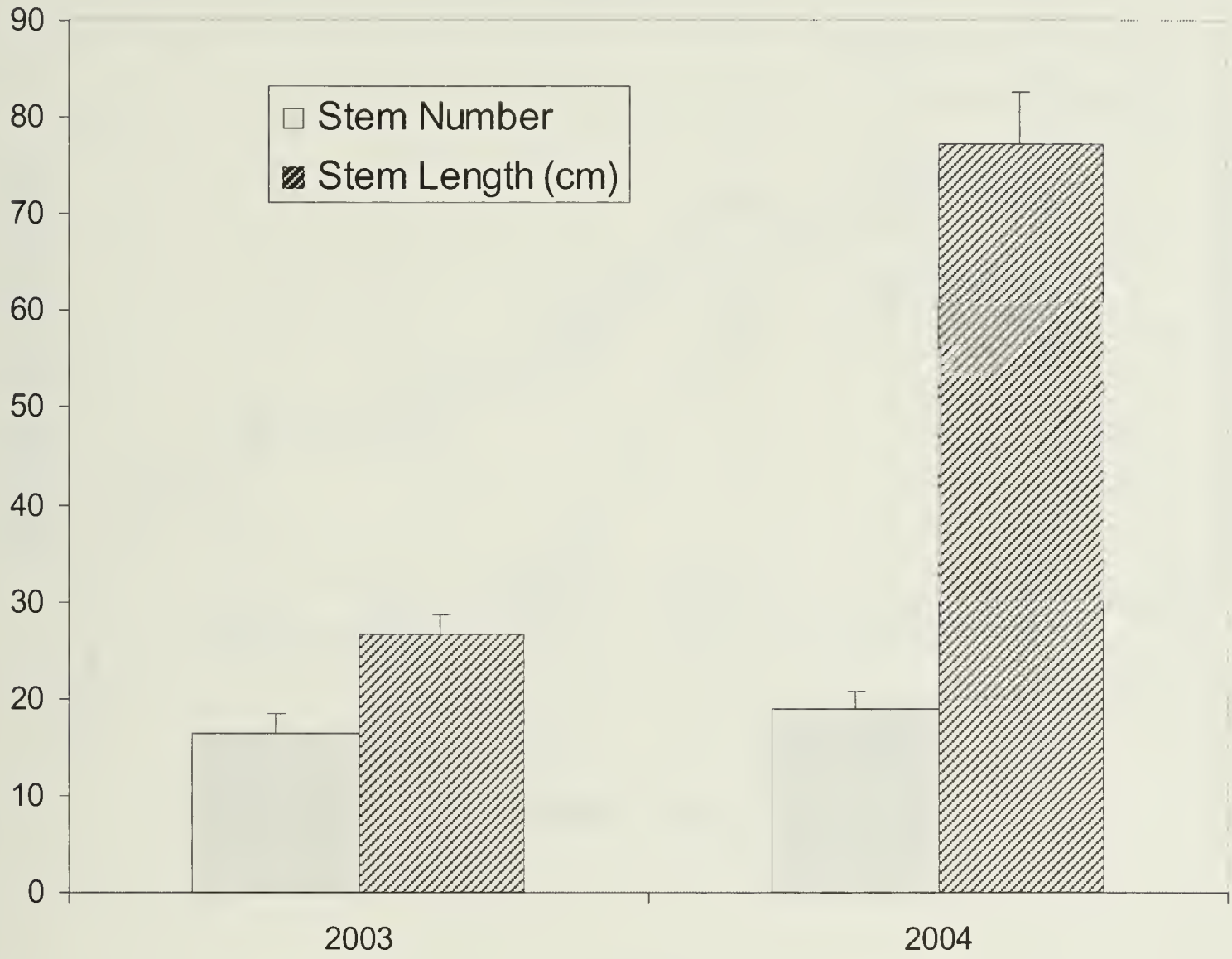


Figure 3. Mean number of *Acer negundo* seedlings per square meter in all transects.

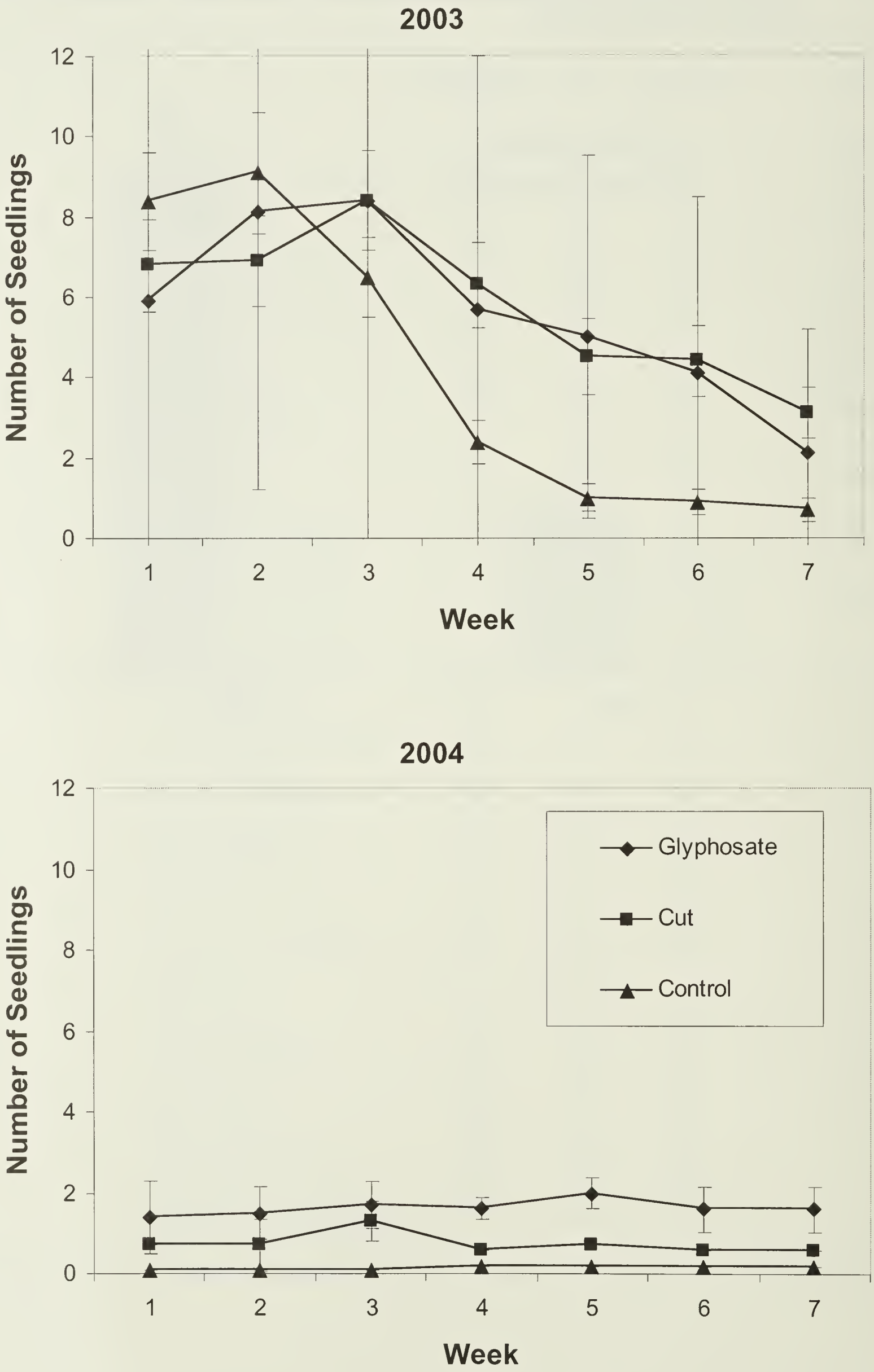
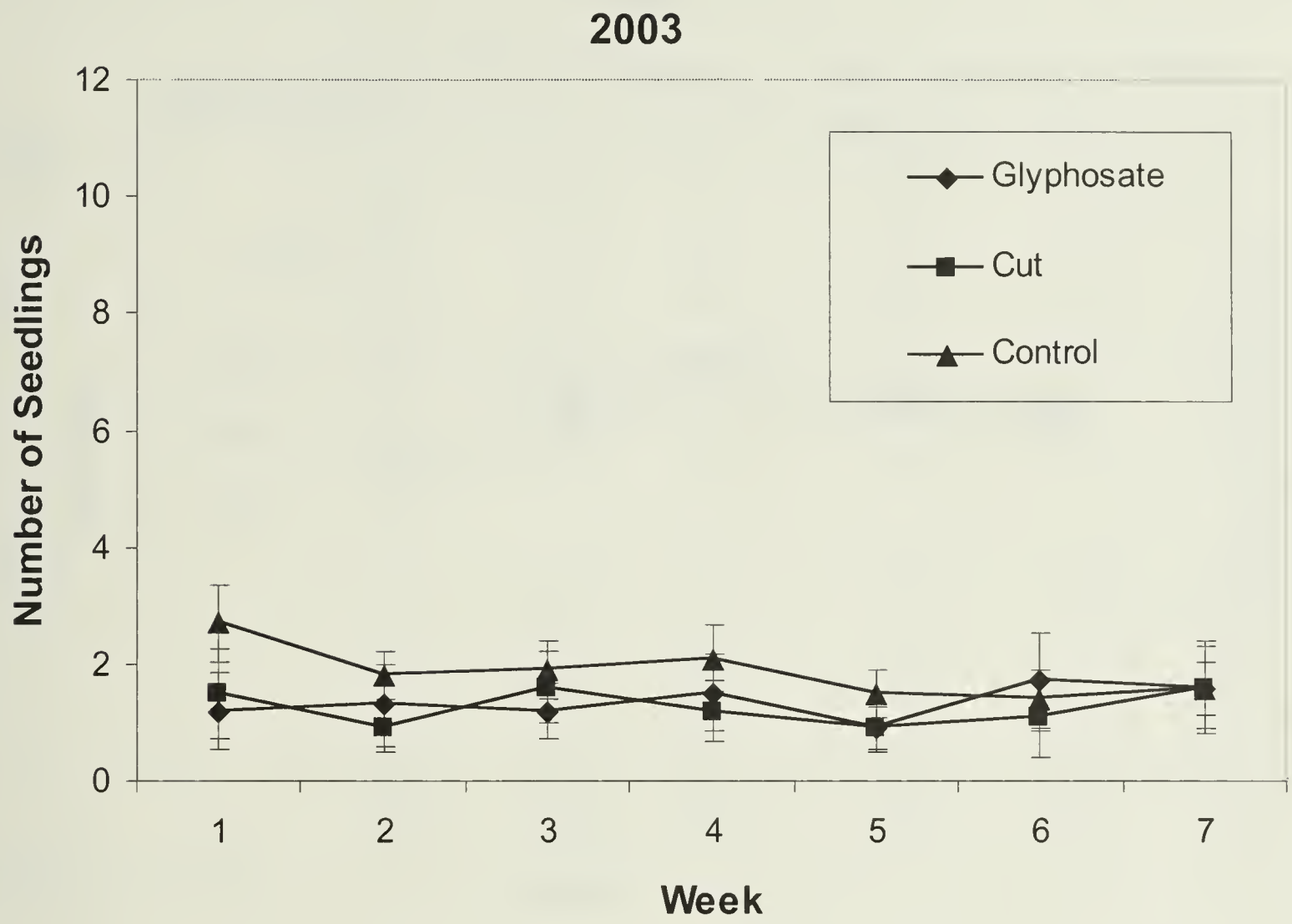


Figure 4. Mean number of *Lonicera maackii* seedlings per square meter in all transects.



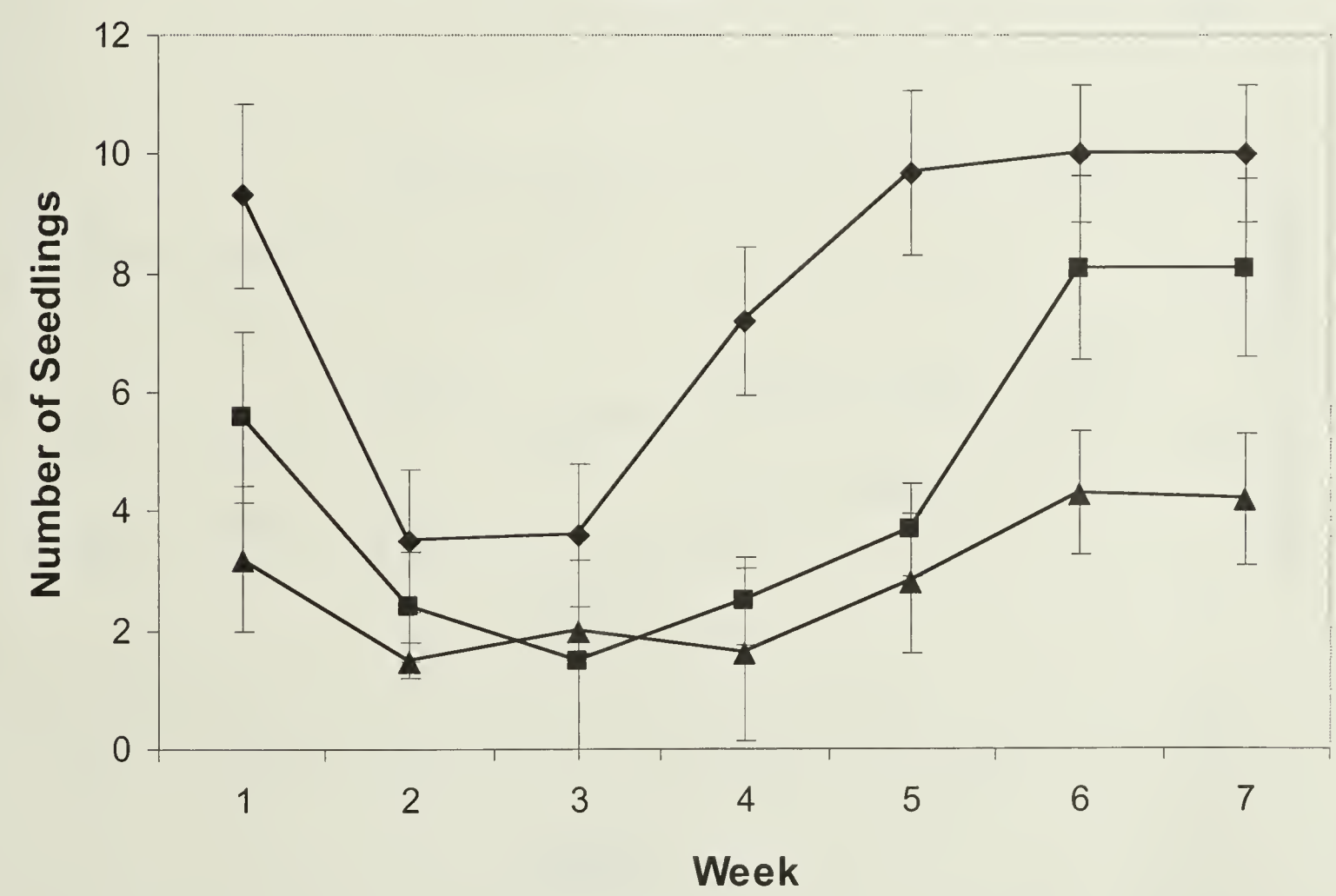


Figure 5. Mean species richness per square meter for all transects.

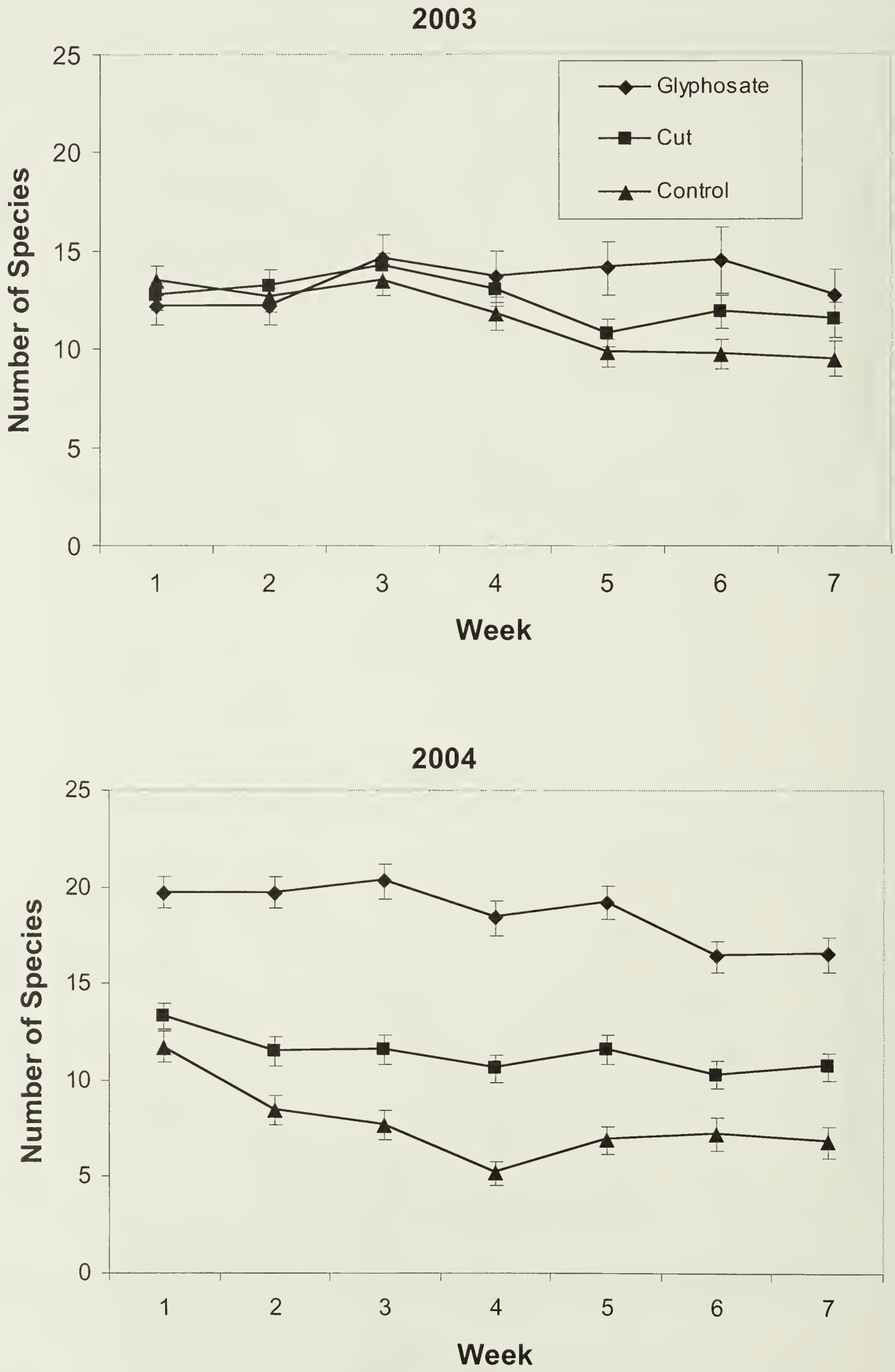


Table 3. Mean light intensities (μmol/m^{2}s^{-1}) and soil temperatures by week and year.

		LIGHT INTENSITY (PPFD)			SOIL TEMPERATURE (^{0}C)		
	week	glyphosate	cut	control	glyphosate	cut	control
2003	1	*	*	*	17.2	*	*
	2	29.0	39.0	9.0	17.4	17.4	15.7
	3	56.0	49.3	14.3	22.4	22.2	19.9
	4	63.0	53.3	15.3	23.4	24.6	21.0
	5	92.7	133.0	45.0	25.9	25.0	22.3
	6	27.0	32.0	7.7	25.9	24.2	22.3
	7	23.0	30.7	10.0	26.7	26.3	24.7
2004	1	19.7	14.0	9.7	19.4	18.9	18.3
	2	9.0	18.7	1.3	17.8	17.6	17.1
	3	57.7	21.3	13.7	21.9	21.4	20.9
	4	24.0	13.7	10.3	23.4	23.4	22.5
	5	22.3	8.0	8.7	21.5	20.9	20.0
	6	32.3	20.0	5.7	21.8	21.3	20.9
	7	24.7	13.7	8.0	22.1	21.8	21.4

* Data not available.

Transactions of the Illinois State Academy of Science
(2005), Volume 98, #1&2, pp. 19-38

received 1/18/05
accepted 6/8/05

Estimates of mtDNA Mutation Frequencies in Wild White-footed Mice Based on Terminal Branch Haplotype Analysis

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ABSTRACT

We applied terminal branch haplotype (TBH) analysis of mitochondrial DNA in wild white-footed mice (*Peromyscus leucopus*) to estimate mutation rates as a measure of genotoxic impact of environmental pollutants. Mice were sampled from two heavy metal contaminated areas at Superfund Sites and two reference sites in northern and southern Illinois. The geographic distribution of mitochondrial DNA haplotypes showed a clear north-south split, however, we found no statistically significant difference in mutation rates as estimated by TBH indices for mice derived from contaminated versus reference sites. These results could be due to mutagen exposure below the critical threshold, or may be indicative of low sensitivity of mtDNA as a molecular marker for genotoxicity.

Key Words: Germline mutation, Hantavirus, Heavy metal, Superfund Sites, Mitochondrial DNA, *Peromyscus leucopus*, Terminal branch haplotype

INTRODUCTION

As abundance of contaminants in the environment has increased, so has exposure of wildlife to those contaminants (Nriagu and Pacyna 1988). Accumulation of heavy metals, organohalogens and other toxicans has been documented in organisms at skeet ranges (Ma 1989; Stansley and Roscoe 1996), military installations (Dickerson et al. 1994; Simini et al. 1995), mining and industrial sites (Bargagli et al. 1997; Laurinolli and Bendell-Young 1996; Lepage and Parker 1988; Pascoe et al. 1994; Tull-Singleton et al. 1994) and among other habitats (Shugart and Theodorakis 1994). Frequently pollutants are present as complex mixtures that present organisms with multiple stressors (Clark et al. 1992; Facemire et al. 1995; Newman and Unger 2003; Shore and Rattner 2001). Few wildlife studies have focused on chronic genetic effects of environmental contaminants,

even though a number of these pollutants are known or suspected genotoxins that cause physical damage (e.g., chromosome breakage, DNA adducts) or mutagenic damage (e.g., nucleotide substitutions, insertion/deletion of nucleotides) to DNA molecules (Ariza and Williams 1996; Butterworth et al. 1995; Hedenskog et al. 1997; Moore et al. 1997).

Genotoxicity studies frequently fail to address two areas: effects of a biologically relevant exposure level and long-term heritable effects. Most studies are based on mutagenic assays performed under controlled lab conditions with cell cultures or lab-bred animals to which predetermined amounts of a suspected chemical are administered (Ariza and Williams 1996; Ledwith et al. 1995; Ogheri et al. 1995). Although some studies make attempts to simulate naturally occurring levels of pollutants present in the environment (Ariza and Williams 1996; Hedenskog et al. 1997), the concentrations of mutagens frequently far exceed those of contaminants present in the environment in order to enhance the treatment effect (Butterworth et al. 1995; Ogheri et al. 1995). Such approaches are essential to determine genotoxic chemicals and to provide guidelines for public health and industrial exposure limits, but they often are limited in assessing risk to exposed wildlife or human populations (Dickerson et al. 1994). For example, natural populations may be exposed to complex mixtures of contaminants, or multiple routes of exposure (e.g., ingestion of contaminated soil due to grooming and foraging) and may vary greatly among species (Beyer et al. 1994). In order to evaluate biologically relevant exposure levels and typical routes of exposure, organisms must be sampled in their natural environment.

Previous ecotoxicological studies have tended to use large-scale measures of DNA alterations (Ieradi et al. 1998; Shugart and Theodorakis 1994; Thies et al. 1996). While useful in monitoring contaminant exposure and genotoxic effects, these measures are not sensitive enough to detect alterations at the molecular level and do not adequately address any increase in the rate of molecular mutations due to contamination. As new molecular techniques became routinely available (e.g., polymerase chain reaction, DNA sequencing), they have been used to examine consequences of genotoxic substances on exposed wildlife (Baker et al. 1996, but see Baker et al. 1997; Chen and Hebert 1999a,b; Ellegren et al. 1997; Somers et al. 2002; Yauk and Quinn 1996; Yauk et al. 2000).

Mitochondrial DNA (mtDNA) sequencing offers another tool to assess genetic damage and its consequences due to environmental contaminants. Several studies have indicated that mtDNA is sensitive to environmental contaminants. Mitochondrial DNA shows much higher levels of DNA adduct formation (Allen and Coombs 1980; Backer and Weinstein 1980) and oxidative DNA damage than nuclear DNA (Richter et al. 1988; Yakes and Van Houten 1997). Mitochondrial DNA, especially the noncoding D-loop (i.e., control region) is ideally suited for phylogenetic reconstruction and estimates of molecular change (Brown 1985; Parsons et al. 1997). The D-loop region is highly variable and is considered the most rapidly evolving region of the mtDNA genome (Saccone et al. 1987). D-loop regions that neither code for proteins nor have a regulatory function are expected to be selectively neutral, ensuring that mutations will not be eliminated from the gene pool, hence they can be detected.

Chen and Hebert (1999a,b) used the variable, selectively neutral D-loop region of mtDNA and developed a novel approach that allowed discrimination between recently

derived mutations and ancestral polymorphism. Because intergenerational mtDNA differences usually arise as single nucleotide changes (Parsons et al. 1997) and newer genealogical derivatives may be separated by only a single or a few generations, Chen and Hebert (1999b) defined terminal branch haplotypes (TBHs) as recently arisen haplotypes (i.e., terminal branches of a phylogeny) that differ from their ancestral haplotypes by a single nucleotide change. They were able to identify TBHs by combining DNA sequencing with phylogenetic analysis. They applied TBH analysis to examine effects of environmental pollutants in brown bullhead (*Ameiurus nebulosus*), which inhabited the same area as herring gulls (*Larus argentatus*) that had increased rates of nuclear minisatellite mutations (Yauk and Quinn 1996). Chen and Hebert (1999b) demonstrated the efficacy of TBH analysis in detecting novel mutations of recent origin. In our study, we modified their TBH approach to examine the frequency of novel mutations in white-footed mice (*Peromyscus leucopus*) that inhabit sites contaminated by heavy metals and corresponding reference sites in Illinois.

MATERIALS AND METHODS

Study species

The white-footed mouse (*Peromyscus leucopus*) is a medium-sized species of *Peromyscus* that is found from southern Canada to southern Mexico east of the Rocky Mountains (Baker 1968). While present in almost every habitat of Illinois, white-footed mice prefer wooded or brushy areas (Hoffmeister 1989). Their population density in Illinois varies depending on location and season (Hoffmeister 1989), but it is sufficiently large to make the species ideal for environmental and genotoxicological assessment. *Peromyscus*, including white-footed mice, have been used previously to study the uptake of environmental contaminants (Clark et al. 1992; Laurinolli and Bendell-Young 1996; Pascoe et al. 1994; Stansley and Roscoe 1996; Tull-Singleton et al. 1994) as well as the potential genetic consequences of such contaminants (McBee and Bickham 1990). Since white-footed mice have been found to disperse up to 300 m (Keane 1990), we made sure that paired contaminated and reference sites were separated by at least 900 m to minimize the possibility of gene flow.

Wild mice were trapped from July to October, 1999 and May to October, 2000 using baited Sherman live-traps. To account for the risk of hantavirus from potentially infected wild mice, we followed published protocols and recommendations for trapping and handling (Mills et al. 1995a,b) as well as quarantine of the mice (Bharadwaj et al. 2000; Botten et al. 2000; Camaioni et al. 2001). In this study we used 46 mice, all of which had tested negative for Sin Nombre virus. Animals were sacrificed under deep anesthesia by cervical dislocation; their carcasses or skeletons were kept as voucher specimens for future reference. All animals were treated in accordance with locally accepted IACUC protocols (ISU IACUC protocol #1-98-12).

Sample sites

White-footed mice were trapped at two contaminated and two reference sites in Illinois (Figure 1 and Table 5). The first contaminated site (i.e., site DePue) was located in northern Illinois on municipal property of the Village of DePue, directly northeast of the DePue/New Jersey Zinc/Mobil Chemical Corporation (NJZMC) site in Bureau County, Illinois. The latter is the location of a former zinc smelter that was declared a Superfund

site and placed on the USEPA National Priorities list by 1999 (US EPA FRL-6338-5 1999). This New Jersey Zinc/Mobil Chemical (NJZMC) site consists of approximately 324 hectares of land in the northeastern part of the Village of DePue. Ecotoxicological assessments by the EPA showed significantly elevated levels of heavy metals (e.g. cadmium, copper, lead, mercury and zinc) in soil and sediment samples taken from DePue Village and the NJZMC industrial site, which ultimately resulted in its designation as Superfund site (IL EPA 1992). The second contaminated site (i.e., site P1) was located in the eastern portion of the Crab Orchard National Wildlife Refuge (CONWR) in Williamson County in southern Illinois. The Crab Orchard National Wildlife Refuge (CONWR) is a 43,000-acre area managed by the U.S. Fish and Wildlife Service. The eastern part of the refuge was occupied for over 60 years by a variety of manufacturing facilities, which resulted in contamination with PCBs, lead and other heavy metals and contaminants related to munitions and explosives manufacturing (Environmental Science and Engineering, Inc. 1994; McKee 1992; US EPA FRL-3187-6 1987). Therefore the eastern half of CONWR was listed as a Superfund site on the USEPA National Priorities list in 1987 (US EPA FRL-3187-6 1987). Several studies documented contaminant concentrations and uptake by wildlife at CONWR (Hite and King 1977; McKee 1992; Woolf et al. 1983). One such study specifically noted the bioaccumulation of lead and PCBs in *P. leucopus* (McKee 1992). Assuming an average generation time of 45 days for white-footed mice and a five months yearly breeding season (King 1968), the long-term presence of potential mutagens at DePue (approximately 100 years) and CONWR (approximately 60 years) could have resulted in exposure of 300 and 200 generations of white-footed mice, respectively.

Reference sites in the north (i.e., GL), and south at CONWR (i.e., CS) were well removed from sources of heavy metal contamination. The Goose Lake site (GL) is located on Goose Lake Prairie State Natural Area (GLPNA), 10 km east of Morris in Grundy County, IL and within 100 km of the contaminated site at DePue. Goose Lake Prairie State Natural Area is the largest remnant prairie remaining in Illinois. The southern reference site CS was located in the western part of the CONWR refuge, about 8 km from the contaminated areas of the eastern half of CONWR. This part of the refuge historically has been free of industrial development and has been managed solely as a wildlife and recreation area since the creation of the refuge.

Soil and tissue analysis for heavy metals

In order to assess the actual levels of heavy metal contaminants, ten soil samples were collected along parallel transects to achieve optimal sampling from each site at Goose Lake, DePue, and the southern control site CS. We used 8x15 cm hand-held stainless steel core sampler to collect soil in accordance with standard protocols (Illinois Department of Natural Resources 1999; Biser et al. 2004). We homogenized and dried all soil samples, which were subsequently analyzed for heavy metals by the staff of the Research and Laboratory Services Program (RLSP) at the Illinois Department of Natural Resources Waste Management Resource Center (IDNR-WMRC). They tested for cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) based on Inductively Coupled Plasma Mass Spectroscopy (ICP-MS); mercury (Hg) concentrations were determined using Cold Vapor Atomic Fluorescence (CVAF) detection. Soil contaminant levels for the southern site P1 were derived from reports compiled by the U.S. Fish and Wildlife Service in compliance with EPA Superfund regulations (Vick 1999). To assess contami-

nant uptake in wild mice, we performed heavy metal analysis of tissue for individuals from our study sites at DePue, P1 and CS; sample sizes were limited to five individuals per site and no tissue analyses were conducted for Goose Lake due to technical and financial constraints. Liver of each animal was collected, weighed to ±0.001 g and stored in acid-washed polypropylene cryovials suitable for subsequent metals analysis as described above.

Our choice of metals to analyze at each contaminated site was informed by published information for contaminants at these sites (Environmental Science and Engineering Inc. 1994; US EPA FRL 3187-6 1987; US EPA FRL-6338-5 1999; Vick 1999). Metals tested at the reference sites were, at a minimum, those that had been documented for its matched contaminated sites (see also Biser et al. 2004). Values are reported as mg/kg wet weight. Soil and tissue samples were analyzed according to standard protocols by the Illinois Department of Natural Resources Waste Management and Research Center (EPA Method 3051 1986; EPA Method 6020 1992; IDNR-WMRC 1999). Concentrations for each metal were compared between the matched experimental and reference sites; except for tissue samples from DePue, which were compared to the southern reference site CS since tissue samples from Goose Lake mice were not available. Because the assumptions for t-tests and ANOVAs could not be met, we utilized nonparametric Mann-Whitney tests for pairwise comparisons and Kruskal-Wallis tests for comparisons between multiple sites in the south; our initial project design included two southern sites (P1 and P4) that were contaminated acc/to the literature, however, we do not present P4 results here as the Kruskal-Wallis test showed elevated contaminant levels for P1, but not P4 when compared to the southern control site CS (SAS Institute, Inc. 1996; Zar 1999).

mtDNA sequencing

Left kidneys were collected for DNA extraction from tissue. The minced tissue was placed in lysis buffer (100mM Tris, 100mM EDTA and 2% SDS) and quickly frozen either in liquid nitrogen or on dry ice until storage at -80°C. DNA for each mouse was extracted from ~25 mg of kidney tissue using the DNeasy Tissue Kit (Qiagen Inc.) (see Table 5 for sample sizes). Two highly variable mtDNA fragments in the replication control (D-loop-containing) region were selected for sequencing (Morzunov et al. 1998). Fragment 1 was amplified with the primer pair MD1 (5'-GTCTAGCTGGACTTTTCAAT TCAAGC-3') and 12ST (5'-GCATTTTCAGT-GCTTTGCTTTATTG-3') while the primers CBT (5'CCGCCATC-AACACCCAAAGCTG-3') and MR1 (5'-CCCTGAAGTAAG AACCAGA-TGCCTG-3') were used for amplification of fragment 2 (Morzunov et al. 1998). Fragments 1 and 2 were 384 bp and 427 bp in length, respectively. Mitochondrial DNA fragments were amplified following Morzunov et al. (1998) and sequenced on an ABI 310 automated sequencer (PE Applied Biosystems) according to standard protocols (Camaioni 2001).

Terminal branch haplotype analysis

Sequence alignment of each mtDNA fragment within and between sites was performed using Sequencher v4.1 (GeneCodes Corporation). Individuals with identical nucleotide sequences were classified as a single haplotype. Common haplotypes and nucleotide differences among haplotypes were determined for each mtDNA fragment by pairwise comparison using MacClade (Madison and Maddison 2000). Correct assignment was confirmed with the program TCS (Clement et al. 2000). Recent mtDNA variants were

determined based on the terminal branch haplotype (TBH) analysis of Chen and Hebert (1999b) with a few modifications. They specify that a haplotype must meet two criteria to be classified as a TBH. First, the haplotype should have a single nucleotide difference (i.e., base pair) from another haplotype within the pool. Secondly, the haplotype had to have been derived from a recent mutational event as indicated by phylogenetic analysis. Single unit insertion and deletion rearrangements (e.g., one base pair deletion, insertion of a dinucleotide repeat in a microsatellite region) were also defined as TBHs if phylogenetic analysis determined that the rearrangement was recently derived (i.e., at a terminal branch of the phylogeny). In addition, we only counted those terminal branch haplotypes that were part of tip clades because we are interested in identifying mutations that could have been caused by the relatively recent exposure to local contaminants.

Since the sequence divergences observed in our study reflect intraspecific variation, and recombination in mtDNA is rare, we employed statistical parsimony analysis (Templeton et al. 1992) using the program TCS (Clement et al. 2000) instead of the neighbor-joining algorithm employed by Chen and Hebert (1999b). The program TCS uses the cladistic approach by Templeton et al. (1992) to create intraspecific gene genealogies by focusing on the similarities among haplotypes that differ minimally (Posada and Crandall 2001), such as by a few variable sites. We created separate nested genealogy networks for fragment 1 and fragment 2 to investigate the phylogenetic relationship and TBH status of haplotypes for each gene region. Based on this nested genealogical network, haplotypes that differed by a single mutational step and occupied terminal branch positions in tip clades were considered of recent origin and given TBH status. If both fragments 1 and 2 had shown a single base pair change in the same individual, then the individual would have been excluded from classification as a TBH for either fragment; however, no such case occurred in this analysis. We tested the null hypothesis that the incidence of terminal branch haplotypes was similar among the paired contaminated and reference sites by using the G-tests of independence (Sokal and Rohlf 1995) on the combined data for fragment 1 and 2.

RESULTS

Metals concentrations in soil and liver tissue

Soil concentrations of the metals for each site are presented in Table 1. Significantly higher levels of heavy metals were found at the DePue site when compared to the reference site at Goose Lake for each metal tested (Cd, Cu, Hg, Pb, Zn). The southern Illinois site P1 showed significantly higher levels of Cd and Hg when compared to the reference site CS. Tissue concentrations at DePue showed significantly higher concentrations for Cd and Pb when compared with the reference site CS; mercury was slightly higher at CS compared to DePue (Table 2). Tissue samples from the reference and contaminated sites in southern Illinois did not differ for the analyzed metals Cr, Pb and Hg (Table 2).

Sequence Variation in mtDNA Fragments 1 and 2

Sequencing revealed 21 variable sites in fragment 1, and 42 variable sites in fragment 2. Fragment 1 contained a greater number of genetic rearrangements, as it contained an insertion, a single nucleotide and a dinucleotide deletion (haplotypes L, N and O, respectively) compared to only one dinucleotide insertion in fragment 2 (haplotypes j, o and p). All other variation was due to nucleotide substitution with a transition to transversion

bias of 9.5:1 for fragment 1 and ~6:1 for fragment 2. Polymorphic sites were more prevalent in fragment 2, which contained 66.6% of the variable sites, and represents the more variable part of the already highly variable D-loop region.

Haplotype frequencies and their distribution

Fifteen haplotypes for white-footed mice were identified for mtDNA fragment 1 (384 bp), and 26 haplotypes for mtDNA fragment 2 (427 bp) out of a total of 46 sequences (Tables 3 and 4). The number of fragment 1 haplotypes was similar at the DePue, CS and P1 sites (Table 3). Goose Lake was the exception with only a third as many. The number of haplotypes for fragment 2 ranged from four to eleven across sites, and Goose Lake again contained the fewest haplotypes (Table 4).

The distribution of haplotypes differed greatly between the two fragments (Tables 3 and 4). For fragment 1, three of four study sites had one dominant haplotypes, representing ~35% or more of the haplotypes present. Fragment 2 showed a larger number of haplotypes, but only Goose Lake contained dominant haplotypes. In addition, haplotypes tended to be private. Over 75% of the haplotypes were present at only one site for both fragments (Tables 3 and 4). Most private haplotypes were present at relatively low frequency (<15%), but a few, such as haplotype aa, were dominant. Finally, there was striking geographic clustering among haplotypes; the distributions of northern and southern haplotypes did not overlap except for haplotype I, which was shared among sites CS, DePue and Goose Lake (Table 3 and 4).

To assess whether our results represented the majority of haplotypes present at each site, the cumulative number of novel haplotypes was plotted against the cumulative number of mice throughout the trapping season. Haplotype number for both fragments 1 and 2 approached saturation with increasing sampling effort implying that few novel haplotypes remained unsampled at each site.

Identification and Quantification of Terminal Branch Haplotypes

The TCS nested network analysis for fragment 1 revealed that only haplotype 'G' showed a one-step nucleotide difference from other haplotypes and occupied a terminal position in a tip clade, defining it as a terminal branch haplotype (Figure 2). The TBH was only present at the contaminated site P1, and neither the reference sites (Goose Lake and CS), nor the second contaminated site at DePue showed this recently derived G haplotype (Tables 3 and 5). Fragment 2 yielded haplotypes 'p' and 'k' that could be classified as TBHs (Figure 3), and they were both found only at the southern Illinois sites (Table 4 and 5). Specifically, haplotype k was only found at the reference site CS, whereas haplotype p was only found at the contaminated site P1 (Table 4 and 5).

Several measures of TBHs, defined by Chen and Hebert (1999b), were utilized to reflect the occurrence of TBHs among the sites (Table 5). The frequency of TBHs per site is indicated by ITBH, or the number of individuals that carry a terminal branch haplotype. Consequently, the Terminal Branch Frequency (TBF) is the ratio of the number of individuals with TBHs (ITBHs) to the sample size (n), and it indicates the spread of the terminal branch haplotypes within a site. The terminal branch index (TBI) is the ratio of TBHs to the sample size (n) and gives a measure of the number of newly arisen variants per site standardized by the sampling effort. Lastly, the number of TBHs compared to the

total haplotypes (TBH/H) measures the frequency of the most recently derived haplotypes among all haplotypes per site, hence is the most relevant measure of mutation rates per site for our study. As the contaminated site at DePue and the Goose Lake reference site showed no terminal branch haplotypes, all measures of recently derived mutations at these two sites were zero. In the south, we documented twice as many TBHs at the contaminated site P1 and as compared to the reference site CS. The ratio of TBH/H, which we use as estimates of recently derived mutations, however, were not significantly elevated at P1 when compared to CS (Table 5).

DISCUSSION

Chen and Hebert (1999b) reconstructed mtDNA genealogies to differentiate novel haplotypes (i.e., terminal branch haplotypes) from historical polymorphisms in natural fish populations of brown bullhead from Lake Ontario. Such discrimination of recently derived mutations from ancestral genetic variation is essential to establish probable cause for increased mutation rates, especially if recent exposure to environmental contaminants is the suspected reason for mutagenesis. By quantifying the proportion of novel haplotypes rather than simply summarizing overall nucleotide diversity, terminal branch haplotype (TBH) analysis provides one of the best tools to estimate mtDNA germline mutations in wildlife that was recently exposed to environmental mutagens.

In our study, we applied TBH analysis of mtDNA sequences to investigate the mutational effects of heavy metals exposure associated with Illinois Superfund sites in natural populations of white-footed mice. We followed Chen and Hebert's approach of combining DNA sequencing and phylogenetic analysis, but instead of applying Neighbor-Joining methods, we used statistical parsimony (Clement et al. 2000; Templeton et al. 1992), which is more appropriate for intraspecific analyses (Clement et al. 2000) and we only counted TBHs that were part of tip clades. For fragment 1 and fragment 2 of the D-loop region, we documented a total of 15 and 26 haplotypes, respectively. We did find a striking geographic north-south split in the distribution of those haplotypes, which most likely reflects independent evolutionary histories of the northern and southern mouse populations in Illinois. Consistent with the rarity of mutational events, few terminal branch haplotypes were found across our study sites, and the percentage of TBHs was not significantly influenced by contaminant exposure for either fragment.

The fact that novel haplotypes (TBHs) are not significantly higher at contaminated sites could be due to the small sample sizes. However, examination of the relationship between sampling effort and haplotype number indicated that few new haplotypes were added with increasing trapping effort. This result suggests that few haplotypes remained undetected within sites and the cumulative frequency of haplotypes per site approached saturation. Therefore, lack of resolution or misrepresentation of TBH incidence rate due to small sample sizes are unlikely explanations for the similarity in unique haplotypes across sites. The latter conclusion is supported by the fact that Chen and Hebert (1999b) could not detect differences in TBHs between their contaminated and reference sites despite very substantial sample sizes. They determined instead that demographic factors, such as population bottlenecks might have resulted in a significant difference of TBI across aquatic habitats. Habitat differences between sample locations were minimized in

our study, and preliminary population analyses suggest no major demographic differences between our sites.

An alternative explanation could be that the bioavailability and bioaccumulation of heavy metals at our study sites were insufficient to cause increased mutagenesis in mitochondrial DNA. Bio-availabilty and accumulation may vary across species, and genotoxicity of contaminants might be lower for mitochondrial than nuclear DNA (Johnson et al. 1999). For example, PCB, PAH and metals contamination of Hamilton Harbour was associated with increased mutations in nuclear minisatellite DNA of birds and mammals but not mitochondrial DNA of brown bullhead (Chen and Hebert 1999b; Somers et al. 2002; Yauk and Quinn 1996). It is difficult to ascertain the exact threshold level of heavy metals that would cause mutations in nuclear or mtDNA, since most previous wildlife studies on the accumulation and acute toxicity of metal contaminants did not quantify genetic damage (Ma 1989; Laurinolli and Bendell-Young 1996; Pascoe et al. 1994; Winder and Bonin 1993). Few studies have performed concurrent metals uptake and mutagenic analyses in the field (Peles and Barrett 1997; Tull-Singleton et al. 1994), hence the implication of heavy metals as genotoxins, even at low levels, is primarily based on lab studies (Ariza and Williams 1996; Codina et al. 1995). Some lab studies have examined the genotoxicity threshold of heavy metals (Codina et al. 1995) and mutagenic chemicals (Ogheri et al. 1995), and a few experiments have reported positive dose-response curves between heavy metal concentration and mutagenic effect (Ariza and Williams 1996; Codina et al. 1995). However, these types of studies are in the minority. It would be beneficial to the wildlife biologist if laboratory studies of mutagenic agents using animal models published not only the *dosage of chemicals applied*, but also the resulting *actual tissue levels* of chemicals. The latter is essential to draw conclusions about biologically relevant threshold levels of contaminants in natural populations where knowledge of exposure has to be inferred from soil and tissue analyses. Also, the fact that lab studies often utilize cell culture or microbial assays (Ariza and Williams 1996; Codina et al. 1995; Moore et al. 1997; Ogheri et al. 1995), and test a single metal or metal compound to determine genotoxicity (Ariza and Williams 1996; Codina et al. 1995; Winder and Bonin 1993), makes it difficult to directly extrapolate lab results to wildlife, which is often exposed to complex mixtures of metals (Chen and Hebert 1999b; Laurinolli and Bendell-Young 1996; Pascoe 1994; Peles and Barrett 1997; Somers et al. 2002; Yauk and Quinn 1996).

In summary, we successfully applied terminal branch haplotype analysis to quantify recently derived mtDNA mutations associated with heavy metal contaminated Superfund Sites and reference sites in Illinois. Sequence analysis of the mtDNA D-loop region revealed a clear geographic split in haplotype distribution, however, contaminant exposure was not associated with increased mtDNA mutation rates as measured by percentage of TBHs. We recommend that future genotoxicology studies on natural populations provide estimates of bioavailabilty and bioaccumulation of contaminants to establish a data base on critical threshold levels of contaminant exposure.

ACKNOWLEDGEMENTS

We would like to acknowledge J. Biser, J. Ohnemus, S. Pasquale and R. Avery for assistance in field work, and R. Xiao, J. Berger, and M. Saavedra for technical assistance. We

thank the Illinois Department of Natural Resources and the USFWS for collection permits and appropriate background information. We are appreciative of the DePue Village Council and the citizens of DePue for access to their properties. Guidance in soil and tissue preparation for metals analysis was provided by M. Piwoni and J. Talbott at the IDNR Waste Management and Research Center. Funding for this research was provided by the US Centers for Disease Control and Prevention grant E11/CCE620225, Sigma Xi, the National Institutes of Heath (NIH; 1 R15 ES10121-01 and RO1 AI41692), the Illinois Department of Natural Resources – Waste Management Research Center, the Illinois State Academy of Sciences, the Beta Lambda Chapter of the Phi Sigma National Biological Honor Society, the Illinois State University Graduate Student Association and the Illinois State University Department of Biological Sciences.

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Figure 1. Approximate location and distances between northern and southern Illinois study sites.

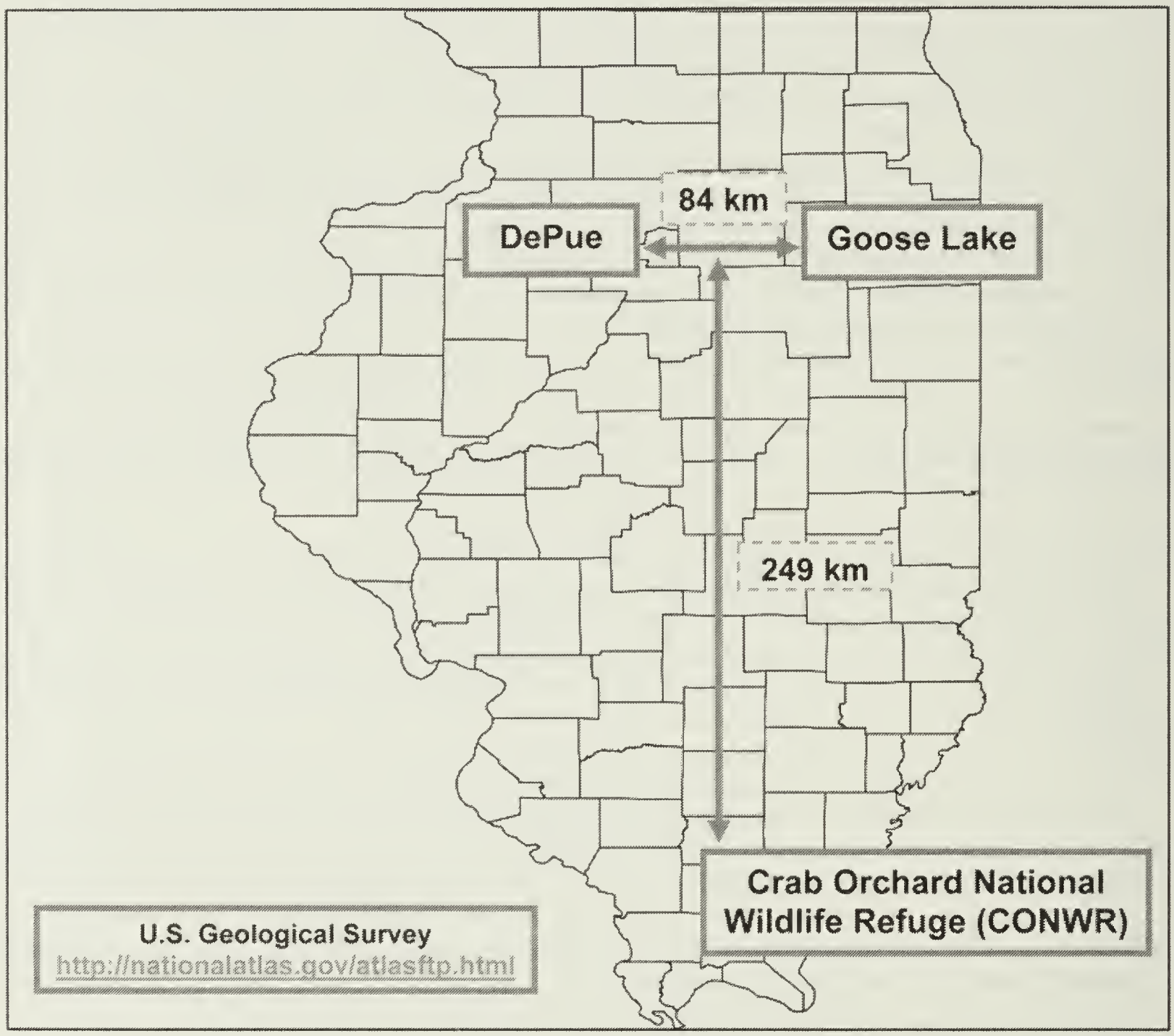

Figure 2. Nested network for fragment 1 (384 bp) haplotypes. Branches indicate 1 mutational step, missing haplotypes are indicated by 'o', haplotypes are indicated by labeled ovals, oval size does not indicate the frequency of individuals per haplotype. Within the total cladogram, haplotypes are equivalent to zero-step clades, clades at one level are clustered into higher level clades, interior clades are connected to more than one clade at the same hierarchical level, tip clades are connected to only one other clade. Haplotypes identified as TBH (i.e., recently derived mutations) had to be part of a tip clade and fulfill criteria identified in text.

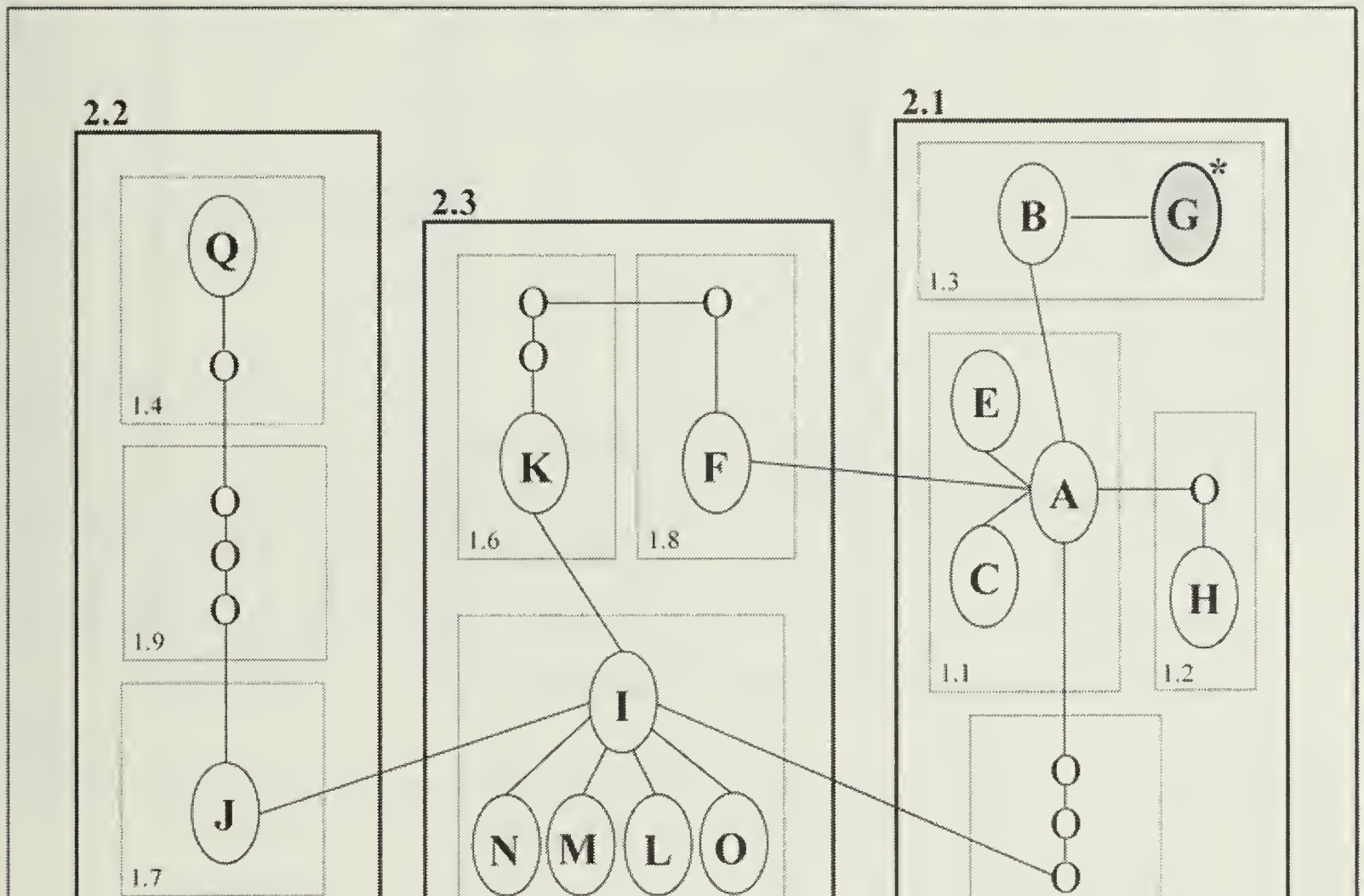

Figure 3. Nested network for fragment 2 (427 bp) haplotypes. Haplotypes identified as TBH had to be part of a tip clade and fulfill criteria identified in text (notation as above). Haplotype 's' was excluded from the network as it exceeded the number of maximal mutational connections justified by 'parsimony' criterion.

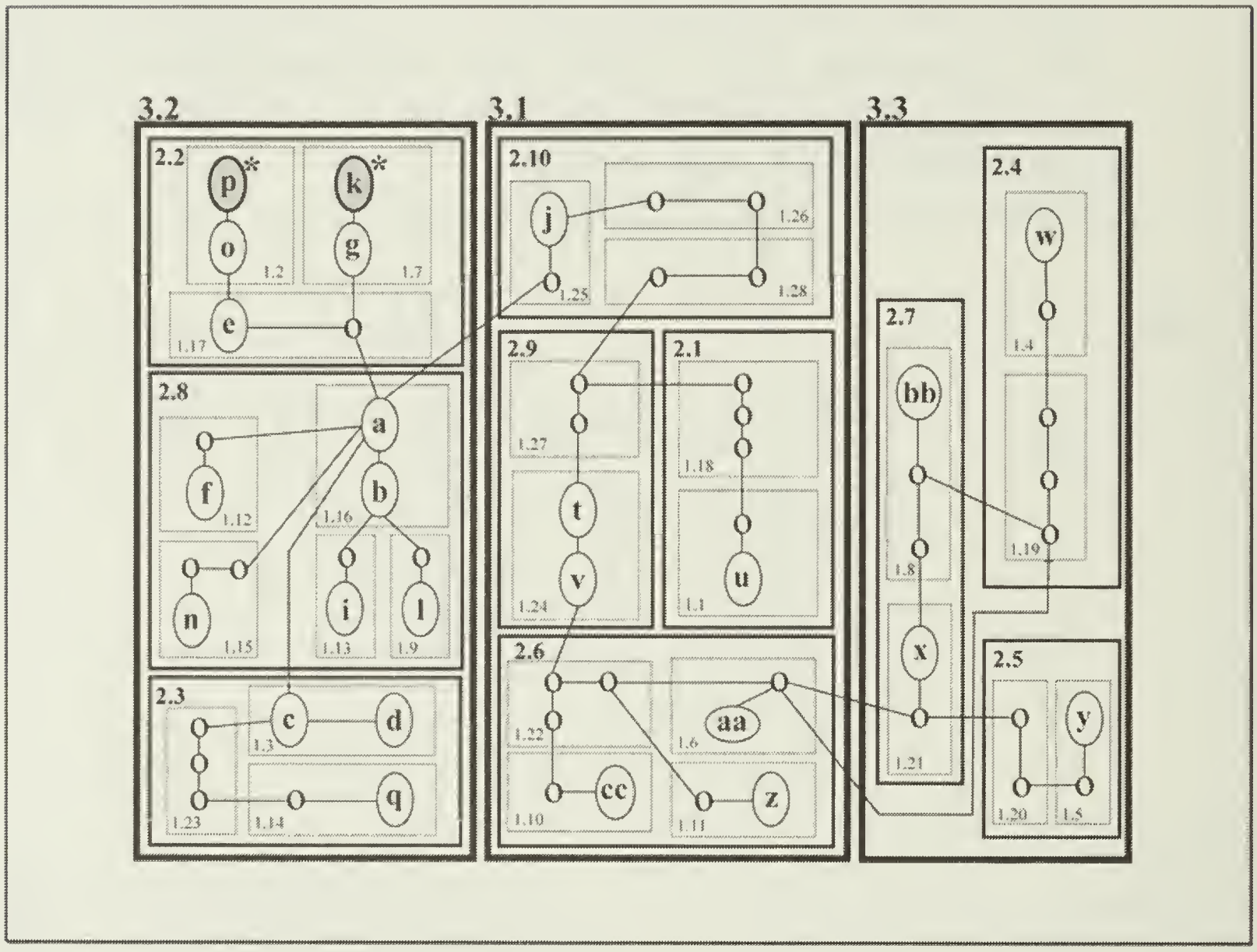

Table 1. Heavy metal concentration of soil collected at the contaminated and reference sites. The dashed line separates the northern and southern sites. An asterisk next to contaminated sites indicates the probability that values differ from each other by chance based on non-parametric statistical test (see text for details).

Site (n)	Type	Units	Statistic	Chromium	Copper	Zinc	Cadmium	Lead	Mercury
P1(2)	soil	mg/kg	MEAN:	31.95 NS	ND	ND	1.15*	26.55 NS	0.11*
			SE:	2.05	ND	ND	0.05	4.95	0.01
			RANGE:	29.9–34.0	ND	ND	1.1-1.2	21.6-31.5	0.1-0.12
CS(10)	soil	mg/kg	MEAN:	22.69	ND	ND	0.12	19.24	0.045
			SE:	0.63	ND	ND	0.01	0.95	0.003
			RANGE:	19–25	ND	ND	<0.1-0.19	16-23	0.027-0.064
DePue (10)	soil	mg/kg	MEAN:	ND	42.9*	2497.31*	38.6*	194.77*	0.046*
			SE:	ND	9.34	828.91	11.34	54.03	0.007
			RANGE:	ND	13 - 98	527-8020	4.7-106	41-466	0.032-0.089
Goose Lake (10)	soil	mg/kg	MEAN:	ND	14.53	59.01	0.32	22.93	0.028
			SE:	ND	0.49	2	0.02	0.73	0.03
			RANGE:	ND	13 - 18	47-67	0.24-0.50	21-28	0.014-0.40

ND = not done; NS = Not significant; * $P < 0.05$

Table 2. Heavy metal concentration of tissue from mice collected at the contaminated and reference sites. The dashed line separates the northern and southern sites; tissue from Goose Lake was not available for this analysis. An asterisk next to contaminated sites indicates the probability that values differ from each other by chance based on non-parametric statistical test (see text for details).

Site (n)	Type	Units	Statistic	Chromium	Copper	Zinc	Cadmium	Lead	Mercury
P1(5)	liver	mg/kg	MEAN:	0.06 NS	ND	ND	ND	0.22 NS	0.0074 NS
			SE:	0.01	ND	ND	ND	0.07	0.0003
			RANGE:	<0.05-0.08	ND	ND	ND	<0.05-0.4	0.007-0.009
CS(5)	liver	mg/kg	MEAN:	0.06	5.58	23.8	0.04	<0.05	0.0072
			SE:	0.004	0.34	0.92	0.01	0	0.0007
			RANGE:	<0.05-0.7	4.6-6.4	22-27	0.02-0.07	<0.05	0.005-0.009
DePue(5)	liver	mg/kg	MEAN:	ND	6.22 NS	27 NS	0.93*	0.24*	0.0022*
			SE:	ND	0.35	1.7	0.38	0.08	0.0002
			RANGE:	ND	5.4-7.1	25-33	0.3-1.7	<0.05-0.4	0.001-0.003

ND = not done; NS = Not significant; * $P < 0.05$

Table 3. The frequency and distribution of 17 mtDNA fragment 1 (384 bp) haplotypes in white-footed mice. Asterisks indicate Terminal Branch Haplotypes based on criteria outlined in text.

	Study Sites			
Haplotypes	P1	CS	DP	GL
A	50.0	28.6	0.0	0.0
B	7.1	21.4	0.0	0.0
C	7.1	0.0	0.0	0.0
E	0.0	7.1	0.0	0.0
F	14.3	0.0	0.0	0.0
G*	14.3	0.0	0.0	0.0
H	0.0	28.6	0.0	0.0
I	0.0	7.1	30.0	62.5
J	0.0	0.0	10.0	0.0
K	0.0	0.0	10.0	0.0
L	0.0	0.0	20.0	0.0
M	0.0	0.0	0.0	37.5
N	7.1	0.0	0.0	0.0
O	0.0	0.0	30.0	0.0
Q	0.0	7.1	0.0	0.0

Table 4. The frequency and distribution of 29 mtDNA fragment 2 (427 bp) haplotypes in white-footed mice. Asterisks indicate Terminal Branch Haplotypes (TBH), which are considered equivalent to recently derived mutations based on criteria outlined in text.

	Study Sites			
Haplotypes	P1	CS	DP	GL
a	0.0	28.6	0.0	0.0
b	7.1	0.0	0.0	0.0
c	7.1	0.0	0.0	0.0
d	14.3	0.0	0.0	0.0
e	14.3	14.3	0.0	0.0
f	14.3	0.0	0.0	0.0
g	7.1	7.1	0.0	0.0
i	0.0	7.1	0.0	0.0
j	0.0	7.1	0.0	0.0
k*	0.0	14.3	0.0	0.0
l	0.0	7.1	0.0	0.0
n	7.1	0.0	0.0	0.0
o	7.1	0.0	0.0	0.0
p*	7.1	0.0	0.0	0.0
q	7.1	0.0	0.0	0.0
s	0.0	7.1	0.0	0.0
t	0.0	0.0	0.0	12.5
u	0.0	7.1	0.0	0.0
v	0.0	0.0	20.0	12.5
w	7.1	0.0	0.0	0.0
x	0.0	0.0	10.0	0.0
y	0.0	0.0	30.0	0.0
z	0.0	0.0	20.0	37.5
aa	0.0	0.0	0.0	37.5
bb	0.0	0.0	10.0	0.0
cc	0.0	0.0	10.0	0.0

Table 5. The terminal branch-haplotype ratio, the terminal branch index (TBI) and terminal branch frequency (TBF) in white-footed mice for fragment 1 (384 bp) and fragment 2 (427 bp) combined. H: Haplotype, ITBH: Individuals with TBH. Terminal Branch Haplotypes are considered equivalent to recently derived mutations based on criteria outlined in text.

Region	Site	Sample (*n*)	No. of TBH	No. of H	No. of ITBH	[a]Ratio of TBH/H	[b]TBI (TBH/n)	TBF (ITBH/n)
North	DePue	10	0	5	0	0.0%	0.0%	0.0%
	Goose Lake	8	0	2	0	0.0%	0.0%	0.0%
South	P1	14	2	17	3	11.8%	14.3%	21.4%
	CS	14	1	15	2	6.7%	7.1%	14.3%

[a,b] not significantly different when comparing reference and contaminated sites

Transactions of the Illinois State Academy of Science
(2005), Volume 98, #1&2, pp. 39-47

received 12/15/04
accepted 4/24/05

A Survey of Anuran Breeding Activity in Illinois, 1986-1989

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ABSTRACT

Amphibian populations have been declining worldwide, with several documented species extinctions in the past two decades. Although monitoring population health can present challenges, surveys of breeding choruses are relatively effective methods for assessing populations and population trends of many frog and toad species. We analyzed data from breeding chorus surveys conducted throughout Illinois from 1986 to 1989. Of the 20 species native to Illinois, 9 were stable or increasing during the survey period whereas the trends for other species were either inconsistent or indicated a decline in population size. To better assess population trends for Illinois frogs, we advocate re-establishment and regular monitoring of choruses, and improved training for volunteers who conduct the surveys.

Keywords: breeding chorus, frog, population trend, regional biodiversity, survey

INTRODUCTION

Declines in amphibian populations have been widely documented over the past decade (Blaustein and Kiesecker 2002, Guerry and Hunter 2002) with particular attention paid to three phenomena: (a) the recent (since the 1980's) increase in reports of species' extinctions; (b) the declines seem to be occurring simultaneously and over great distances; and, (c) populations in protected, natural areas are declining (Collins and Storfer 2003). Among the hypotheses advanced to explain amphibian declines, habitat alteration has arguably had the greatest impact on population stability for species found in Illinois (Stebbins and Cohen 1995). Habitat destruction and forest fragmentation (usually resulting from land use change) have often led to the isolation of populations in small parcels of habitat having variable quality (deMaynadier and Hunter 1999, Laan and Verboom 1990). Having a smaller size and little to no contact with other individuals (because of fragmentation), isolated populations can become increasingly susceptible to stochastic extinction processes (Sjögren 1991). In addition, geographic isolates often occupy marginal habitat which, due to its poor quality, may compromise the longevity of the population.

Long-term population monitoring is crucial to the understanding of both pattern and process in population declines. For anurans, the monitoring process is made easier by the fact that population health can be qualitatively assessed by surveying breeding choruses. In Illinois, the most extended survey of this type to date took place between 1986 and 1989. During this effort, 19 of the 20 frog species native to Illinois were documented by surveying breeding choruses along 65 routes each 16 km in length. We analyzed this data for these anuran species with the objectives of increasing the knowledge of their distribution, encouraging participation in their continual protection, and increasing interest in frog populations among naturalists.

MATERIALS & METHODS

During the breeding season, volunteer surveryors across the state drove along one of 65 pre-determined 16-km routes (Fig. 1). Each occasion of driving along the route constituted a run; three runs were each separated by approximately one month. Surveyors were asked to complete their runs during the following time intervals: early spring covering the period from late March to mid-April; late spring covering the period from late April to mid-May; and, summer covering the period from late May to mid-June.

During each run, a volunteer would stop every 0.8 km along the route and listen for breeding calls of anurans. The intensity of the calls heard at each stop was used to quantify the abundance of each anuran species at that site. The following guidelines were use to rate the intensity of the chorus and, therefore, a subjective assessment of the number of individual frogs present: 1 = individuals can be counted; there is space between calls; 2 = calls of individuals are distinguishable but some calls overlap; and, 3 = full chorus; calls are constant, continuous, and overlapping. If background noise (e.g., traffic, trains, etc.) prevented the surveyor from hearing anuran chorus activity, the surveyor moved to the next stop along the route where chorusing could be heard. At each stop, the surveyor also recorded the time and temperature (± 1 °C). Descriptions of habitat quality and the distance from the roadside to the nearest wetland (even a water-filled ditch) were not recorded.

When analyzing the data, we noted that volunteers occasionally recorded a species being heard in a county where there was no previous record for that species (Phillips et al. 1999). To allow for the possibility that the species might be rare and potentially unrecorded at the edge of its known range, we considered the record accurate if it was within two counties of the known distribution for the species. If the species was reported in an area further than two counties away from its known distribution in the state, we omitted these data from this analysis.

In spite of the volunteers' effort to collect quantitative abundance (in the form of chorus intensity ratings), data were too irregular to assess local or statewide population trends. Additionally, because some frog species were actively breeding in more than one of the three sampling periods within each year, we pooled all data for each species across routes and runs (within years). Thus, the results reported below reflect inter-annual population trends for each species across the entire state and not trends specific to any region or particular populations. Population trends for each species were plotted over all years (even if absent during a particular year) and Pearson's regressions were performed for each spe-

cies to express the strength of each trend. We did not describe a population trend for any species where the coefficient of correlation for these regressions was less than 0.40, or if the species was observed for fewer than three years within the survey period.

RESULTS & DISCUSSION

Volunteers who participated as surveyors in this study included private individuals, college students, and personnel from the Illinois Department of Natural Resources (IDNR). Of the 65 established routes, 21 were not surveyed and five routes (3 in the north-eastern, and 2 in the central, portions of Illinois) were surveyed all four years. The remaining 39 routes were surveyed 1-3 times. Figures 2 through 4 summarize the percent occurrence by year of all species found in Illinois.

Four species of toads are known from Illinois, two of which are found statewide. Trends for these species were variable, with no consistent pattern of change (Table 1; Fig. 2). *Scaphiopus holbrookii* was not observed during the study period due to the lack of survey routes crossing its known distribution in the state. Healthy populations have been observed in extreme southern Illinois since the time period of this study (S. Mullin, pers. obs.). Populations of *Bufo fowleri* increased, whereas no trends were apparent for either *B. americanus* or *Gastrophryne carolinensis*.

Of the four smaller hylid species in Illinois (Fig. 3a), *P. crucifer* and *A. crepitans* increased, *P. triseriata* decreased, but no trend was apparent for *P. streckeri illinoiensis* and it remained relatively rare. Two species of treefrogs are found statewide and two are found in the southern extreme of Illinois. Of these four species, occurrence of *Hyla cinerea* and *H. chrysoscelis* increased, whereas trends for *H. versicolor* and *H. avivoca* were not apparent (Fig. 3b).

Populations of *Rana blairi*, *R. areolata*, *R. sphenocephala* and *R. catesbeiana* increased during the study period (Fig. 4a,b). In contrast, population trends for *R. pipiens*, *R. clamitans*, *R. sylvatica*, and *R. palustris* were not apparent during the study period, with the latter two species being relatively uncommon.

Lack of consistent route coverage (less than 3 runs per year) and lack of data entirely from nearly one third of all routes hampers more definitive assessments of Illinois frog and toad populations. We suggest that any future efforts attempt a broader and more consistent coverage of more wetland areas across the state so that isolated populations (perhaps those representing uncommon species in Illinois) are not overlooked. Additionally, increased consistency within years would improve the quality of future survey data (e.g., seasonal changes, abundance estimates, etc.).

Another possible problem during the survey was the misidentification of certain species of anurans. Volunteer surveyors' experience in identifying frog/toad calls ranged widely and, in spite of their having been provided with instructional materials and tapes of frog calls, errors occurred in the data set. We excluded 36 out of 1314 total records (2.74 %) due to the observed species being reported well outside its known distribution. Additionally, in the few instances where the volunteer described the microhabitat for a particular stop along a route, an observed frog species was occasionally associated with an incorrect

habitat type. The North American Amphibian Monitoring Program (NAAMP; <http://www.pwrc.usgs.gov/naamp/>) has recently established an internet-based guide to the various frog breeding calls as well as a tool for assessing a prospective volunteer's ability to correctly identify a frog species based on its calls. For future survey efforts in Illinois, we recommend that IDNR adopt a recruitment policy that encourages volunteers to train themselves on the NAAMP website prior to surveying anuran breeding choruses.

ACKNOWLEDGMENTS

We are grateful to R. Szafoni and the Illinois Department of Natural Resources for providing the opportunity to examine the data set generated during the study period. Funding for this study and publication costs were provided by the Undergraduate Research Council of Eastern Illinois University and Illinois Chapter of The Nature Conservancy.

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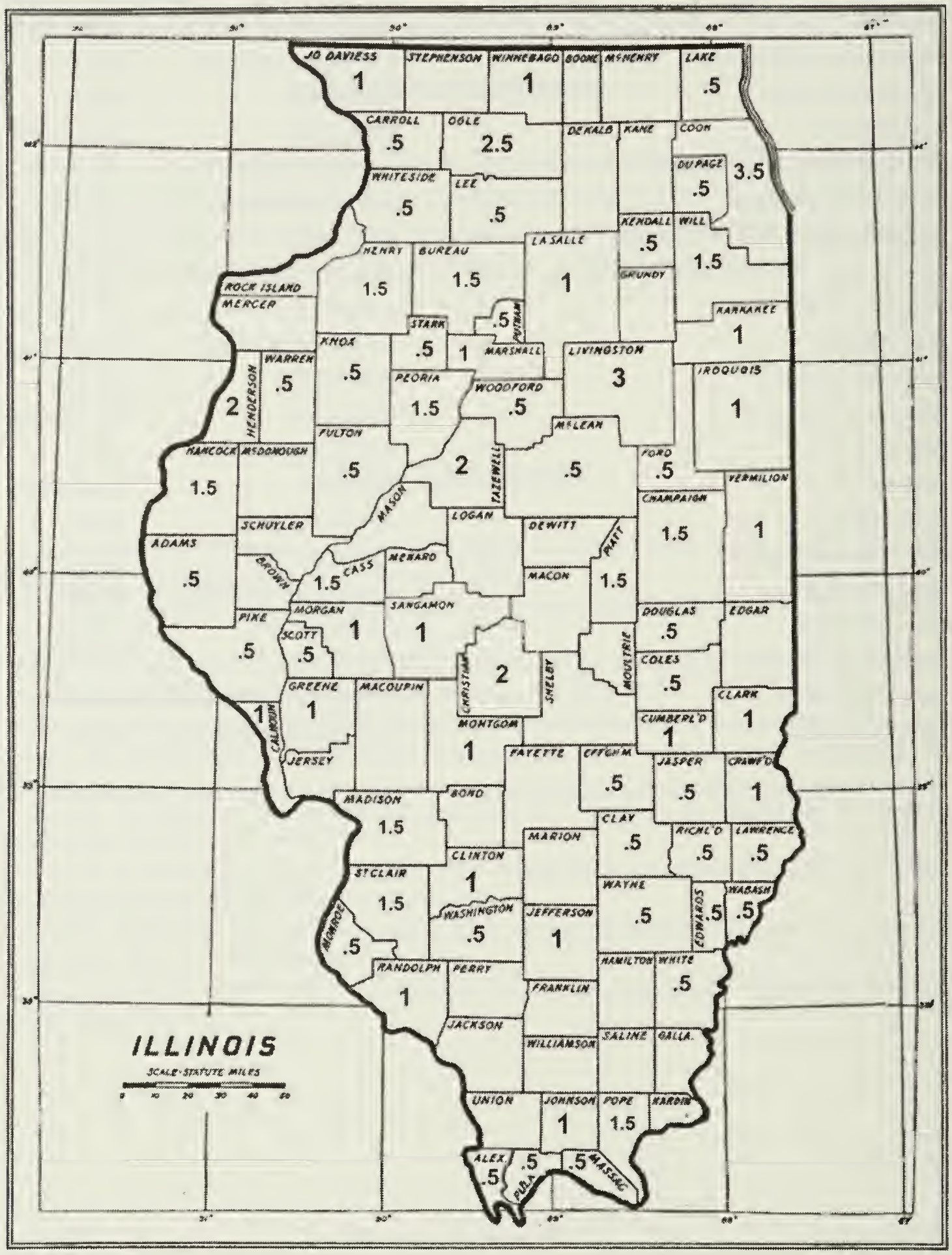
Table 1. Population trends of anurans in Illinois breeding choruses as determined by road-side surveys conducted along 65 routes from 1986 to 1989.

Species	Years observed	Illinois distribution	Population trend
Scaphiopus holbrooki	0	southern extreme	n/a
Bufo americanus	4	statewide	none
Bufo fowleri	4	statewide	increasing
Gastrophryne carolinensis	1	southern extreme	none
Pseudacris crucifer	4	scattered statewide	increasing
Pseudacris triseriata triseriata	4	statewide	decreasing
Pseudacris streckeri illinoensis	2	isolated populations	none
Acris crepitans	4	statewide	increasing
Hyla cinerea	4	southern extreme	increasing
Hyla versicolor	4	statewide	none
Hyla chrysoscelis	4	statewide	increasing
Hyla avivoca	4	southern extreme	none
Rana blairi	3	central	increasing
Rana pipiens	4	northern half	none
Rana sphenocephala	4	southern half	increasing
Rana areolata	3	southern extreme	increasing
Rana palustris	1	southern half	none
Rana catesbeiana	4	statewide	increasing
Rana clamitans	4	scattered statewide	none
Rana sylvatica	1	isolated populations	none

Figure 1. Map of the Illinois counties where anuran breeding chorus surveys were conducted between 1986 and 1989. The number within each county corresponds to the number of routes contained within that county. Values of "0.5" indicate a portion of one route contained within that county.



1500—1-40—18234-E

Figure 2. Percent of routes reporting breeding calls of three different species of anurans in Illinois from 1986 to 1989. Coefficients of correlation (r^2) are based on Pearson's regressions.

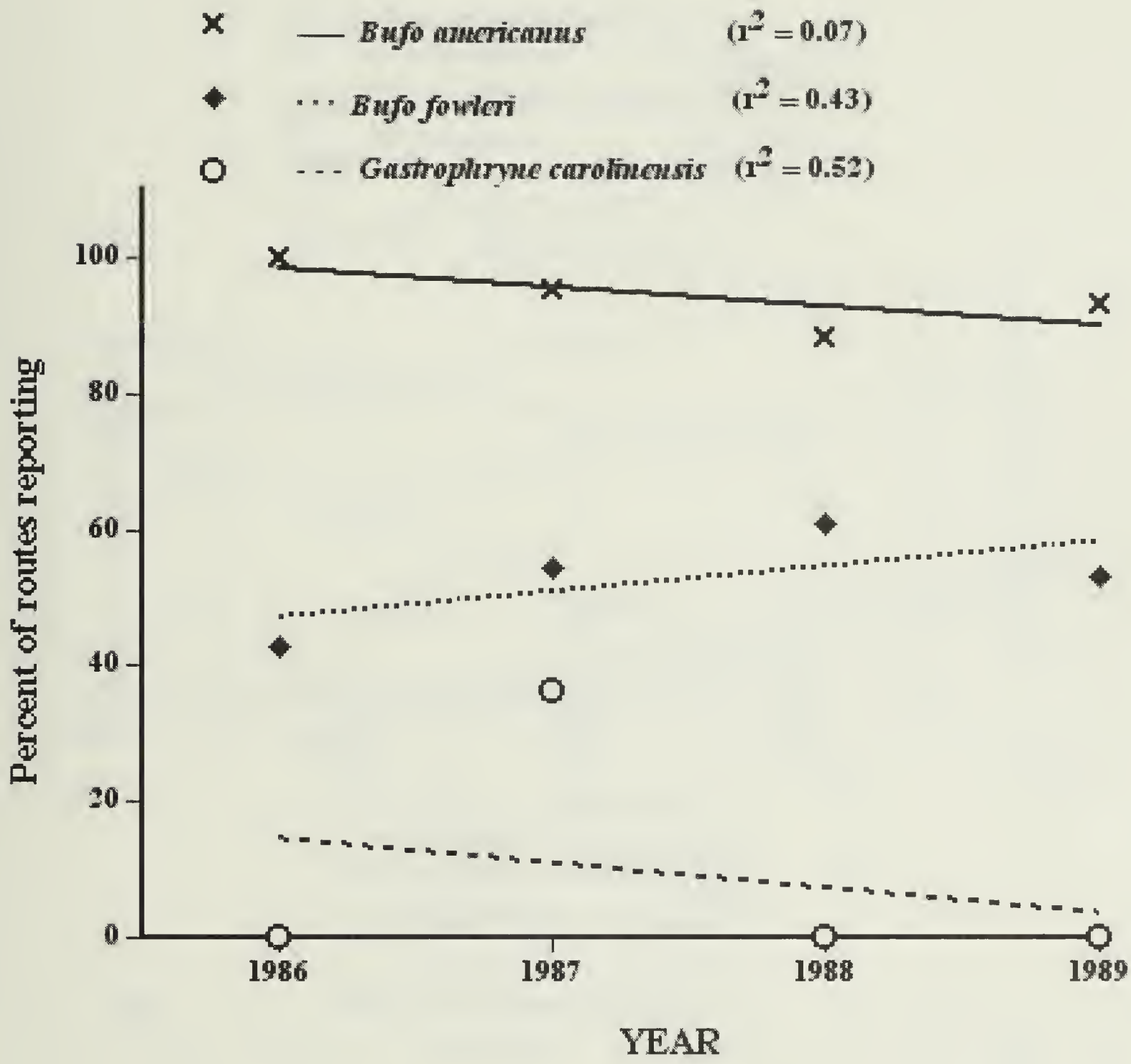


Figure 3. Percent of routes reporting breeding calls of four species of small hylid frogs (A) and four species of treefrogs (B) in Illinois from 1986 to 1989. Coefficients of correlation (r^2) are based on Pearson's regressions.

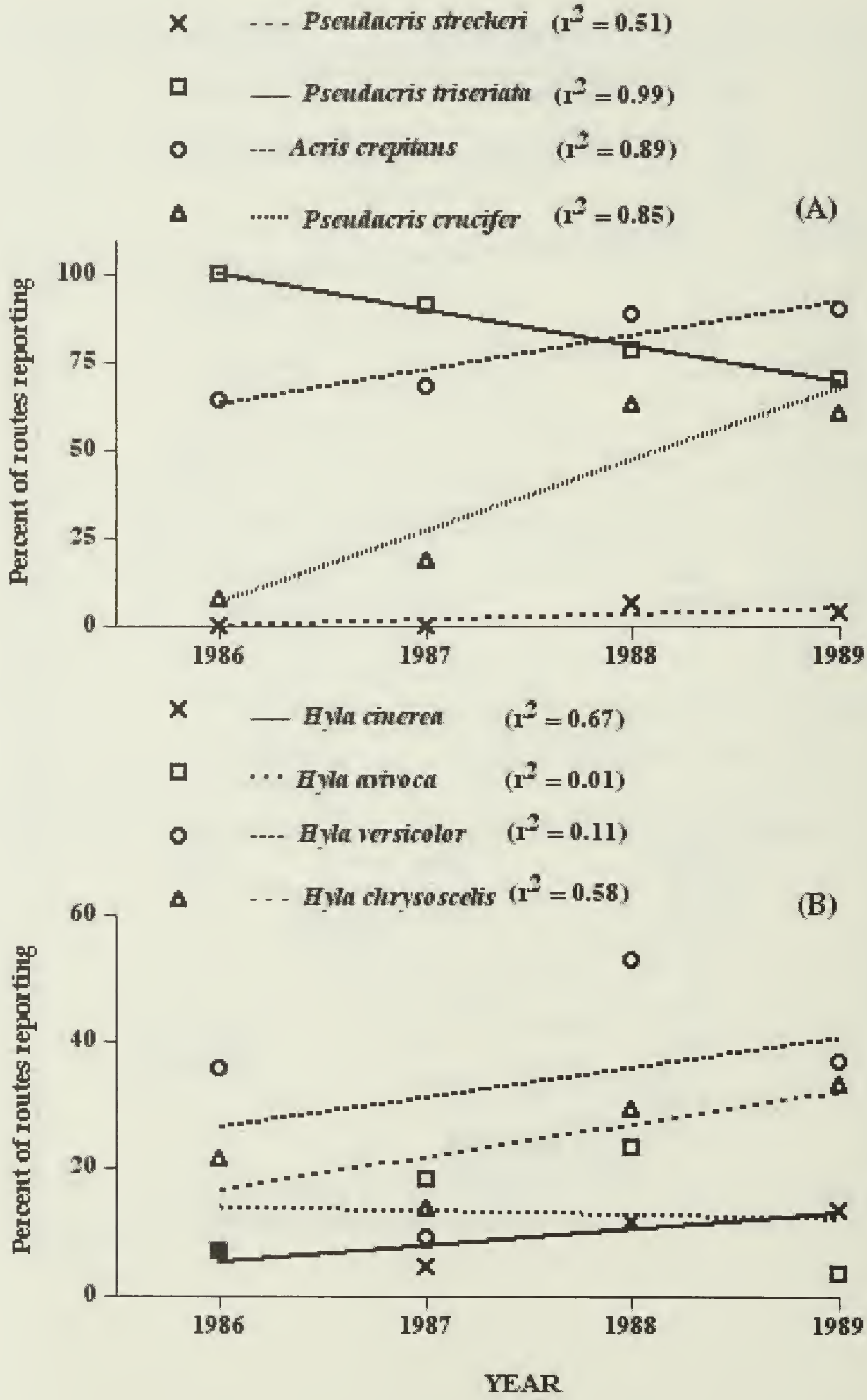
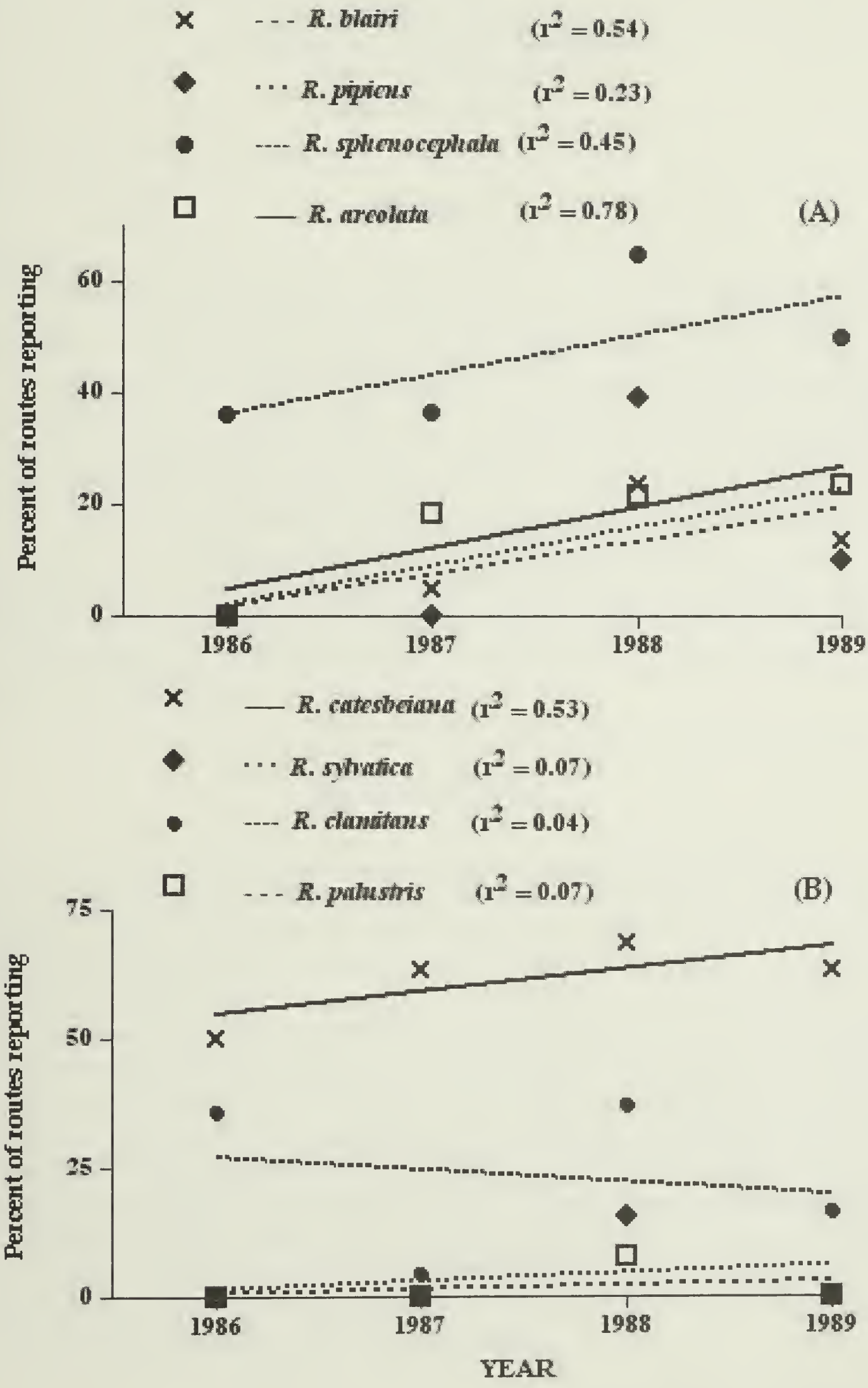


Figure 4. Percent of routes reporting breeding calls of eight different species of ranid frogs (*Rana* sp.; leopard and crayfish frogs in [A], other ranid frogs in [B]) in Illinois from 1986 to 1989. Coefficients of correlation (r^2) are based on Pearson's regressions.



Transactions of the Illinois State Academy of Science
(2005), Volume 98, #1&2, pp. 49-54

received 12/2/04
accepted 4/24/05

Use of National Weather Station Temperature Records in Field Studies

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ABSTRACT

Temperatures at the soil surface under dense vegetative cover were compared with those from a National Weather Station located 6.6 km away over a period of 14 years in east-central Illinois. Comparisons were made during periods of very low (<0 C), very high (>30 C), and intermediate (5-29 C) temperatures. All temperatures were significantly different between the two sites. Mean daily temperatures recorded at the National Weather Station during periods of very low temperatures were 13.4 C lower than those at the vegetative-moderated soil surface. There was no correlation of mean daily minimum temperatures at the National Weather Station during periods of very low temperatures with those under the vegetation. Mean daily maximum temperatures were 6.1 C and 8.1 C higher at the National Weather Station than at the soil surface during periods of moderate and high temperatures. Usage of temperature data from distant National Weather Stations is inappropriate for estimating effects of temperatures on small mammals living under dense vegetative cover.

INTRODUCTION

Analyses of data from field studies of small mammals frequently test effects of weather conditions on demographic variables such as survival, activity, dispersal, and reproduction (Madison, 1985; Kriegsfeld et al., 2000; Jackson et al., 2001). Time constraints and limited resources often prohibit establishment and monitoring of weather stations within the study site during the course of the study. Or, such analyses are conducted as an afterthought so as to obtain additional information from the data sets. Researchers, therefore, often rely on weather data from existing National Weather Stations located some distance from the site for these analyses (Brady and Slade, 2004). In addition to bias resulting from local differences in weather conditions at the study site and National Weather Station, serious bias results from positioning of recording instruments 1 m above the surface at National Weather Stations. This is an especially important concern when the animals studied limit their activity to below dense vegetation. There is the potential for temperatures below such insulative cover to differ from those in the air above (Geiger, 1965). The magnitude of differences in temperatures measured at National Weather Stations distant from the study area have not been documented.

During the course of a demographic study of small mammals in east-central Illinois (Getz et al., 2001), a temperature station continuously recorded temperatures at the soil surface below a dense stand of bluegrass (*Poa pratensis*), under which there was a mat of dead bluegrass litter. The subjects of this study, prairie vole (*Microtus ochrogaster*), meadow vole (*M. pennsylvanicus*), and short-tailed shrew (*Blarina brevicauda*), utilize small (≈3 cm in diameter) runways formed through the dense mat of vegetation and litter on the soil surface. Often the runways are worn ≈1 cm into the soil.

OBJECTIVE

The objective of this study was to compare temperatures from under the vegetation at a field site with those from a National Weather Station located 6.6 km SW of the study site. Specifically, tested were: (1) the magnitude of differences in temperatures as recorded by a distant weather station from those measured under vegetative cover and (2) the correlation of temperatures recorded at the weather station with those under vegetative cover.

MATERIALS AND METHODS

Study sites

The small mammal study site was located within a former bluegrass pasture in the University of Illinois Biological Research Area ("Phillips Tract"), 6 km NE of Urbana, Illinois (40°15'N, 88°28'W). The pasture was released from grazing in June 1971; there was dense vegetative cover, including a mat of dead bluegrass litter, by autumn 1971. Sunlight penetration to the soil surface in the site was only 3.2 ± 0.2% of full sunlight (Getz et al., 2005). The National Weather Station, maintained by the Illinois State Water Survey, was on the Morrow Research Plots on the University of Illinois campus. The Morrow plot weather station was located approximately 120 m to the west and east of tall campus buildings, and 50 m to the north and 90 m to the south of buildings; the moderating effects of campus buildings on wind currents and thus temperature regimens was minimal. The field station was located approximately 200 m southwest of a 25 ha mature deciduous forest and 100 m east of a 20 ha site in which invading trees reached heights of 10 m by the time the temperature study was completed.

Methods

A Bristol 3-pen recording thermograph was located at a site where vegetation appeared typical of the general study area. Each pen was connected to a 1.8-m cable lead with a temperature probe at the end. The three probes were positioned on the soil surface under undisturbed litter and vegetation at 120° angles from the recorder. The recorder was placed in a wooden shelter for protection from the elements. Temperatures were recorded continuously by ink pens on a circular paper chart. The charts were changed and ink added weekly. Temperature data were obtained from 10 July 1972 through 29 April 1986. National Weather Station records for these dates were provided by the Illinois State Water Survey.

Data analyses

Data selected for analysis were from three general temperature regimens, as recorded at the National Weather Station, during the 14 years the field temperature recorder was operating: (1) from periods of very low temperatures, when daily maximum temperatures

were <0 C; (2) from periods of very high temperatures, when daily maximum temperatures were >30 C; and (3) from periods of moderate temperatures, when daily maximum temperatures were 5-29 C. Specific blocks of time used in the analyses were restricted to periods with at least five consecutive days that met the above requirements. Daily maximum and minimum temperatures, and amount of fluctuation were compiled from the soil surface records. Daily maximum and minimum temperatures were determined by averaging the three pen traces. Data for the same days were compiled from the National Weather Station records.

Statistical analyses

Significance of differences in maximum and minimum temperatures and amplitudes of fluctuations between the National Weather Station and field measurements were determined by *t*-tests (Zar 1999). Data for periods of high and moderate temperatures were log-transformed. Minimum temperature data sets involved negative numbers and were not log-transformed. Comparisons of transformed and untransformed data sets without negative entries indicated *t*-values on untransformed data were almost identical to those on log-transformed data. Correlation analyses of the high and moderate temperature data sets utilized Pearson's *r* (Zar 1999). Because of negative numbers, Kendall's *tau* (Zar 1999) was used to test for correlations between the National Weather Station and field data during low temperature periods.

RESULTS AND DISCUSSION

All comparisons of temperatures recorded at the National Weather Station differed significantly from those under the vegetation in the study site (Table 1). The greatest magnitude of difference between National Weather Station and soil surface temperatures in the field were mean daily minimum temperatures during periods of very low temperatures, 13.6 C lower at the National Weather Station than under the vegetation in the study site (Table 1). Maximum daily temperatures varied by only 3.9 C between the National Weather Station and field during periods of very low temperatures. During periods of moderate and very high temperatures, mean daily maximum temperatures were 6.2 C and 8.1 C higher at the National Weather Station than at the soil surface in the field, respectively. Mean daily minimum temperatures at the National Weather Station varied little from those recorded at the weather station during these two periods, 1.5 C and 1.8 C, respectively (Table 1).

Amplitudes of fluctuation were greater at the National Weather Station than were those at the soil surface (Table 1). Those at the soil surface differed the most (10.4 C) during periods of very low temperatures and least when temperatures were very high (6.3 C). Daily fluctuations at the National Weather Station differed among the three temperature regimes by only 1.2 C; those at the soil surface differed among the three temperature regimes by 5.3 C, with the least daily fluctuation during periods of low temperatures (Table 1). Except for daily minimum temperatures and amplitudes of fluctuation during periods of very low temperatures, mean daily maximum and minimum temperatures, as well as daily fluctuations in temperatures, at the National Weather Station were significantly correlated with those under the vegetation (Table 1).

Because the small mammals in this study were active at the soil surface, under a dense mat of vegetation, sub-soil temperatures might be most representative of those to which the small mammals were exposed. Although soil temperatures are not normally a part of the records from National Weather Stations, temperature data from 10 cm below the surface at the Morrow Plot station were available for representative periods during the present study. During periods of exceptionally low temperatures, daily minimum soil temperatures (-0.9 ± .2 C) reflected most closely both daily maximum (-0.6 ± .1 C) and minimum (-0.8 ± .1 C) temperatures at the soil surface in the field (daily maximum soil temperature at the Morrow Plot station was +0.8 ± .2 C). During periods of exceptionally high temperatures, daily minimum soil temperatures 10 cm below the surface at the Morrow Plot station most closely reflected daily maximum surface temperatures at the field site (23.9 ± .2 C and 24.3 ± .3 C, respectively; daily maximum soil temperatures were 26.6 ± .3 C; minimum surface temperatures at the field site were 20.1 ± .4 C).

From these observations, use of temperature data from a distant National Weather Station to estimate potential stresses on animals living under dense vegetation has obvious limitations and limited utility. National Weather Station records vastly exaggerate potential low-temperature stresses encountered by the animals and amplitudes of temperature fluctuation during periods of very low temperatures. Further, mean daily maximum temperatures during periods of high and moderate temperatures differed markedly between the National Weather Station and soils surface. Except for minimum temperatures and amplitudes of fluctuation during periods of very low temperatures, temperatures recorded at the National Weather Station were positively correlated with those at the soil surface. It is, however, periods of low-temperature stresses that typically are most important in estimating effects of temperatures on physiological stresses, survival, reproduction, and behavior of small mammals (McDevitt and Speakman, 1994; Kriegsfeld et al., 2000; Jackson et al., 2001).

CONCLUSIONS

The results of this study suggest temperature data from distant National Weather Stations are inappropriate for estimating temperature stresses encountered by small mammals living under dense vegetation. If available, soil temperature data from 10 cm below the surface might be utilized to approximate surface temperatures under vegetation at a field site. Unfortunately, soil temperatures are not typically recorded at National Weather Stations. Methods for measuring temperatures at the local site and at the level at which the subject animals live should be utilized.

ACKNOWLEDGEMENTS

The study was supported in part by grants NSF DEB 78-25864 and NIH HD 09328 to LLG and by the University of Illinois School of Life Sciences and Graduate College Research Board. Thanks are extended to L. Verner, J. Edgington, M. Schmierbach, and P. Mankin for maintaining the field temperature station.

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Table 1. Comparison of temperatures (mean daily °C ± S.E.) recorded at a National Weather Station with those at the soil surface under a dense mat of bluegrass (*Poa pratensis*) vegetation, in east-central Illinois.

Temperature regime	Weather station[e]	Field surface[e]	Correlations *r/tau*[f]	P
Low temperature periods[a] (152)[d]				
Daily maximum temperatures	-5.5 ± 0.4	-1.6 ± 0.3	0.137	0.018
Daily minimum temperatures	-15.5 ± 0.4	-1.9 ± 0.3	0.074	0.200
Daily fluctuations	10.9 ± 0.8	0.5 ± 0.1	0.054	0.403
Moderate temperature periods[b] (141)[d]				
Daily maximum temperatures	21.0 ± 0.7	14.8 ± 0.7	0.777	<0.001
Daily minimum temperatures	9.2 ± 0.6	10.7 ± 0.6	0.750	<0.001
Daily fluctuations	11.4 ± 0.3	3.8 ± 0.2	0.392	<0.001
High temperature periods[c] (159)[d]				
Daily maximum temperatures	32.7 ± 0.1	24.6 ± 0.3	0.258	0.001
Daily minimum temperatures	20.7 ± 0.2	18.9 ± 0.2	0.376	<0.001
Daily fluctuations	12.1 ± 0.2	5.8 ± 0.2	0.223	0.005

[a] Low temperature periods, daily maximum temperature at weather station <0 C.

[b] Moderate temperature periods, daily maximum 5-29 C.

[c] High temperature periods, daily maximum >30 C.

[d] Number of days in each sample in parentheses.

[e] All differences between weather station and field means are significant at <0.001; t-test).

[f] Correlations: moderate and high temperature periods, Pearson's *r*; low temperature periods, Kendall's *tau*.

Transactions of the Illinois State Academy of Science
(2005), Volume 98, #1&2, pp. 55-62

received 10/27/04
accepted 4/24/05

Population Characteristics of the Gray Fox (*Urocyon cinereoargenteus*) in Southern Illinois during the Late 1970s

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ABSTRACT

We obtained 217 gray fox carcasses from fur buyers in southwestern Illinois during the winters of 1978-79 and 1979-80, a time of comparatively high fur prices and harvests. Individuals with an upper canine pulp cavity width ratio >.40 were identified as juveniles (0-1 year old); remaining specimens were aged by cementum annuli counts. For the 2 years combined, there were 106 (48.8%) males and 111 (51.2%) females; the sex ratio did not differ from 1:1 (x^2=0.074, P>0.05). The mean number of placental scars for female gray foxes was 3.24, and the reproductive rate was 81.1%. Juveniles comprised 56.2% (n=122) of the 2-year sample; remaining animals were 1 to 8 years old with the mean age of 1.69 years. The percentage of juveniles we found was slightly higher, but similar to 2 previous studies in southern Illinois during the mid-1950s and early 1960s when more moderate fur prices and harvests existed. Survivorship curves and mean ages from the earlier time period and our sample were similar. Increased harvests of gray foxes during the late 1970s did not appear to alter the population characteristics of the species in southern Illinois from those of the mid-1950s and early 1960s when more moderate harvests occurred.

Key words: age structure, demographics, gray fox, reproduction, sex ratio, *Urocyon cinereoargenteus*

INTRODUCTION

Anthropogenic factors such as harvest levels can affect sex and age ratios of foxes (Cypher 2003). Layne (1958) and Lindenfelser (1978) provided demographic information for gray foxes (*Urocyon cinereoargenteus*) collected in southern Illinois during the mid-1950s and early 1960s. No official harvest records were kept at that time, but based on the limited information available, Lindenfelser (1978:19) considered harvests to be "relatively light." One fur buyer cooperating with our study told of purchasing only a few hundred gray foxes each winter in the mid-1950s and early 1960s (C. Zanders, personal communication).

Fur prices and harvest levels increased dramatically for most furbearers, including gray foxes, from the mid- to late 1970s. The mean price per gray fox pelt in the 1975-76 fur season was $16.00 (Hubert 1976). In 1979-80, the mean price was $43.80, an increase of >170% (Hubert 1980). At the same time, the statewide harvest of gray foxes increased from 7,132 to 10,547 (Hubert 1976, 1980). During this time period, the same fur buyer cited above indicated that he purchased over 2,000 gray fox pelts annually from hunters and trappers.

Our objectives were to determine population characteristics of gray foxes in southern Illinois during this time of high annual harvests and to compare them to that of the mid-1950s and early 1960s.

MATERIALS AND METHODS

We obtained gray fox carcasses from three fur buyers in Randolph County, Illinois during December – January 1978-79 and 1979-80. Cooperating fur buyers purchased gray foxes harvested in southern Illinois, including counties from which both Layne (1958) and Lindenfelser (1978) had collected specimens.

Each specimen was assigned an identification number and its sex was recorded. The animal's rostrum containing the upper canine teeth was removed from the carcass with a hand saw and placed in a plastic bag. The uterus of each female was removed, similarly bagged, and frozen for later analysis.

Canine teeth were removed from the rostrums after boiling for about 20 minutes. A canine from each gray fox was sawed off at the gumline with a Dremel™ Roto-drill equipped with a 1-mm thick, 25-mm diameter carborundum saw, a dental "separating disk." (Mention of a product or company does not imply endorsement.) Each crown's maximum pulp cavity width (a) and maximum tooth width (b) was measured with a calibrated binocular dissecting scope, and a pulp cavity width ratio (a/b) was calculated for each specimen. Individuals with a pulp cavity width ratio >.40 were identified as juveniles (0-1 year old) (Root and Payne 1984). Matson's Laboratory, LLC (P.O. Box 308, Milltown, MT 59851) sectioned the remaining teeth and provided cementum annuli counts.

After thawing, each uterus was split longitudinally and placental scars (PS) were counted. To prevent counting the PS of aborted or the previous year's pups, only the darkest scars were counted (Lindstrom 1981).

Reproductive rates for females 1-2 years of age (subadults) and >2 years of age (adults) were calculated. Survivorship curves and mean ages were also calculated, and along with various age and sex groupings of our data, the results were compared to those provided by Layne (1958) and Lindenfelser (1978).

RESULTS

We examined 217 gray fox carcasses; 106 males and 111 females. The ratio of males to females, 0.95:1, did not differ from 1:1 (x^2=0.074, P>0.05). Most (n=122; 56.2%) of the

animals were juveniles; the remainder ranged from ≥1 to 8 years of age (Table 1). The sample's mean age was 1.69 years based on 0-1 year = 0.75, 1-2 years = 1.75, etc.

PS were found in 43 (81.1%) of 53 subadult and adult females; the mean PS count was 3.24 (range 1-5). The mean number of PS for 19 of 25 subadults, 3.05, was not significantly different from that for 22 of 26 adults, 3.41 (t=2.023, P>0.05). Two specimens, both adults, had PS, but exact counts were not possible; they were excluded when determining and comparing means.

DISCUSSION

Past studies have reported lower fecundity for subadult foxes than for adults (Wood 1958, Storm, Andrews, Phillips, Bishop, Siniff, and Tester 1976). In our study, a greater proportion of adult females had PS than did subadults (85.7% versus 76.0%, respectively). While adults had a higher mean number of PS than subadults, the difference was not significant.

Coyotes (*Canis latrans*) are known to respond to increased harvest pressure with compensatory reproduction, i.e., larger litter sizes (Knowlton 1972, Jean and Bergeron 1984). We did not detect this phenomenon in our sample of gray foxes from the late 1970s. The mean PS count of our combined subadult and adult female gray foxes was 3.24, similar to that reported by Layne (1958) in the mid-1950s (3.62). Our mean PS count was also similar to that reported for a protected population in South Carolina (3.6; Weston and Brisbin 2003). Means for harvested populations in other parts of the United States, as summarized by Weston and Brisbin (2003), varied from 3.7-4.6 PS.

We found no PS in nearly 19% of females ≥1 year of age. While Layne (1958) recorded 2% of the females ≥1 year of age in his sample as barren, he included females which had been collected through June and those with either PS or embryos when determining this figure. If only winter-harvested females and PS counts alone had been considered, it is probable that the percent of barren females in his sample would have been larger. Weston and Brisbin (2003) reported a barren rate of 11.1% for a protected population in South Carolina; this rate was determined from counts of both PS and embryos.

Our sample of 217 gray foxes from the late 1970s had a male-female sex ratio of 0.95:1 (Table 2). Layne (1958) noted 114 males from the 218 gray foxes in his mid-1950s study and Lindenfelser (1978) recorded 133 males among the 204 gray foxes he examined. The latter study's male-female sex ratio was significantly different from 1:1 (Table 2).

Other than 2 road-killed foxes, hunters supplied all the specimens for both of the previous southern Illinois studies (Layne 1958, Lindenfelser 1978). During a study of red foxes (*Vulpes vulpes*), Storm et al. (1976) noted that more males were harvested via hunting than females and more females were trapped than males, but neither difference was significant. Lindenfelser (1978) speculated that he collected more male gray foxes (Table 2) because of their higher susceptibility to hunting.

Hubert (1978, 1979) recorded the sex of 94 gray foxes obtained from fur buyers in north-central Illinois concurrent with our study. He noted that greater than two-thirds of his

specimens had been killed by hunters with the remainder harvested by trappers. He reported a greater percentage of males (60.6%) than our study, but the sex ratio did not differ significantly from 1:1 (x^2=3.84, P>0.05).

Our sample consisted of both trapped and hunted gray foxes, probably mostly hunted. Although we noted a lower percentage of males in our study than did Layne (1958) and Lindenfelser (1978), like Layne's study, our male-female ratio did not differ significantly from 1:1 (Table 2) indicating little apparent effect from the increased harvests of the late 1970s.

Lindenfelser (1978) aged his specimens by counting cementum annuli in the animal's first lower premolar; he noted the oldest specimen was 9 years of age. The mean age of Lindenfelser's (1978) specimens and that of our sample were 1.72 years and 1.69 years, respectively. Despite higher fur prices and thus, increased harvests of the late 1970s, the mean ages from the two studies were not significantly different (t=1.966, P>0.05).

Layne (1958) did not age most of his specimens, but determined that 28 of 54 (51.9%) females collected from December – February were juveniles based on the appearance of their reproductive organs and teats. The age structure for Lindenfelser's (1978) sample was 49.0% juveniles, 28.4% subadults, and 22.5% adults. Overall survivorship curves were similar for both studies despite differences in harvest levels during the two time periods (Figure 1).

Age structure differed markedly for a protected population in South Carolina, where juveniles comprised 37.2% of the population, subadults 10.3%, and adults 52.6% (Weston and Brisbin 2003). An earlier study at the same site, conducted soon after harvest was suspended, showed age ratios closer to ours: 62.5% juveniles, 21.7% subadults, and 15.8% adults (Wood and Odum 1964). While changes in habitat might have contributed to this shift in age structure, Weston and Brisbin (2003) considered differences in harvest regimes as a plausible explanation. We concluded that relative differences in harvest regimes had little impact on age structure of gray foxes in southern Illinois during the 1950s and 1960s, when harvest was moderate, and the late 1970s, when harvest peaked.

Among red foxes, Storm et al. (1976) found a lower percentage of juveniles taken by hunting and a higher percentage harvested by trapping. Lindenfelser (1978) speculated that during a time of increased harvest pressure, more juveniles would be taken due to their greater vulnerability to trapping. A portion of the animals in our sample was from trappers, possibly leading to a slightly higher percentage of juveniles in our sample than the previous southern Illinois studies (Table 2).

Jean and Bergeron (1984) and others have noted that increased harvest pressure on coyotes leads to more juveniles within the population. Although we observed a greater percentage of juveniles in our sample of gray foxes, the age ratio was similar to those of the earlier southern Illinois studies (Layne 1958; x^2=0.59, P>0.05 and Lindenfelser 1978; x^2=1.82, P>0.05).

Higher fur prices of the late 1970s led to increased harvests of all furbearers, including gray foxes. It appears that such harvests did not dramatically alter the southern Illinois

gray fox population characteristics from those of the mid-1950s and early 1960s when more moderate harvests occurred.

Our findings provide the most recent description of gray fox age, sex, and reproductive characteristics in Illinois. Statewide harvest of gray foxes has declined from a peak of 10,547 during 1979-80 (Hubert 1980) to approximately 100 during recent years (Illinois Department of Natural Resources, unpublished data). This dramatic change creates an interesting basis for comparison to our study. However, collecting an adequate sample size is not logistically feasible in the foreseeable future.

ACKNOWLEDGMENTS

This project was funded in part by Federal Aid in Wildlife Projects W-49-R and W-99-R, the U.S. Fish and Wildlife Service, and Illinois Department of Natural Resources, cooperating. We thank fur buyers H. Schaffner, C. Zanders, and G. Zanders for saving gray fox carcasses for us, E. Zwicker for assisting with statistical analysis, and D. Major, J. Weston, A. Woolf, and E. Zwicker for reviewing earlier drafts of the manuscript.

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Figure 1. Survivorship curves of a sample of 217 gray foxes collected 1978-79 and 1979-80 and of a previous study in southern Illinois (Lindenfelser 1978).

Table 1. Age classes of 217 gray foxes collected 1978-79 and 1979-80 in southern Illinois.

Age Class	1978-79	1979-80	Combined Sample
0-1	43	79	122
1-2	10	31	41
2-3	4	19	23
3-4	3	17	20
4-5	0	3	3
5-6	0	3	3
6-7	0	0	0
7-8	2	1	3
8-9	1	0	1
	63	153*	216*

* One specimen, >1 year old aged via pulp cavity width ratio (see text), not included

Table 2. Male-female and juvenile-adult ratios of 217 gray foxes collected 1978-79 and 1979-80 and of two previous studies in southern Illinois.

	Sample Size	Male-Female Ratios	Juvenile-Adult[a] Ratios
Present study	217	0.95 : 1	1.29 : 1
Layne (1958)	218	1.10 : 1	1.08 : 1
Lindenfelser (1978)	204	1.87 : 1[b]	0.98 : 1

[a] Juvenile = 0-1 year old; Adult = >1 year old

[b] significantly differs from 1 : 1 (x^e=18.24, P<0.05)

Transactions of the Illinois State Academy of Science
(2005), Volume 98, #1&2, pp. 63-73

received 11/10/04
accepted 4/24/05

Fishes of the Chicago Region: A Review of the Dennison and Illinois Natural History Survey Collections

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ABSTRACT

The Illinois Natural History Survey collection of fishes has vouchered a large number of specimens from northeastern Illinois including the urban Chicago area, Fox River drainage, and Kankakee River drainage. Based on specimens collected since 1990, the area has 119 native species, 17 non-native species, and 13 hybrid combinations. In particular, we report on the records recently obtained with the acquisition of a collection of fishes donated by Mr. Sam Dennison of the Metropolitan Water Reclamation District of Greater Chicago. We make general observations on the fauna and on the status of several non-native species.

INTRODUCTION

Almost 100 years ago, Meek and Hildebrand (1910) published a list of fishes that occurred within 50 miles of Chicago. Since that time there have been relatively few published species lists for the region although lists have been presented in governmental reports or on sub-regions of the area (Greenfield et al., 1984; Savitz et al., 1996) or indirectly as part of larger works (Hubbs and Lagler, 1941; Smith, 1979; Retzer, 2005).

The waterways of the Chicago area have a long history of alteration and abuse (Forbes and Richardson, 1920; Smith, 1971). Indeed, Meek and Hildebrand (1910), knowing that the fauna was undergoing drastic changes, were prompted to document the fauna at that time. The high human population density of the area led to severe water quality problems that were not addressed in a meaningful way until the 1970s with the advent of effective water quality treatment (Lerczak et al., 1992). With the passage of the Clean Water Act, water quality in the Chicago area has improved allowing improvement in the fish community (Pegg and McClelland, 2004). In addition, the connection between Lake Michigan and the Illinois and Mississippi River drainages initially resulted in extremely poor water quality in the Illinois River and now has resulted in a movement of fishes between the basins (Burr et al., 1996; Pegg and McClelland, 2004). This movement includes the dispersal of non-native species from one basin to the other. Movement of invasive species

in either direction has the potential of drastically impacting one of the basins (see Mills et al., 1994 for an excellent review of non-native species in the Great Lakes).

Collection records based on vouchered specimens provide solid data on distributions and changes in distributions of native and non-native fish species and hybrids in a region. Herein, we present a list of native species, non-native species, and hybrids for the Chicago area based on 643 samples from 403 locations in the region and represented by vouchered specimens in the Illinois Natural History Survey (INHS) Fish Collection. The area of study includes the Fox, Kankakee, and Des Plaines rivers and tributaries, Chicago canal system, and Lake Michigan (Fig. 1). We also comment on the current state of the fish assemblage within the urban Chicago area (Des Plaines River and tributaries, Chicago canal system, and Lake Michigan). The recent acquisition of a sizable collection of fishes donated by Mr. Samuel Dennison to the INHS prompted us to present a comprehensive list of fishes and make general observations on the urban Chicago area and the non-native species. Mr. Dennison built the collection of fishes from approximately 1970 to 2000 as part of his duties at the Metropolitan Water Reclamation District of Greater Chicago. This area is of particular interest as it encompasses the most heavily urbanized and altered subregion (ie., the urban Chicago area) in northeastern Illinois. Mr. Dennison had deposited some of his early materials at the INHS in the mid- 1990s. More recently, he donated a substantial collection to the INHS so that the specimens could be permanently vouchered and available to the scientific community, resource managers, and the general public. Most of this material was collected during the late 1990s.

METHODS AND MATERIALS

Specimens donated by Mr. Dennison were processed in accordance with commonly accepted natural history collection procedures. The materials were stored in mostly unsorted but unique collections (a unique collection being a mixture of species captured at the same site on the same date). About 25% of the specimens were stored originally in Carosafe. While this storage medium is safe to handle, specimens lose color and texture when in this medium for a long period. Another 25% of the collections were stored in formalin and these were soaked in water to remove the formalin. About 50% of the materials were found to be in alcohol. All specimens were switched to 70% ethanol for long-term storage.

Collections were sorted by species and catalogued into the INHS collection and incorporated into permanent holdings. Initial identifications were made by an undergraduate student worker and verified by the staff ichthyologist. Basic information (ie., location, date collected) for the cataloged materials is available by Web access of the fish collection at the INHS Web site (www.inhs.uiuc.edu).

In addition, data on field collecting methods were recorded and this supplemental information is available from the INHS Fish Collection. In general, electrofishing and seining were the methods employed.

The INHS database was searched to obtain a list of taxa for the study area from collections made during and after 1990. This search included non-Dennison records that also have been added to the INHS Fish Collection.

RESULTS

The Dennison collection contained 153 samples from 40 sites. We processed 4600 specimens containing 49 species and 8 hybrids.

Of the 49 species, 38 were native and 11 were non-native species. The five most common species, in terms of abundance of individuals, were the bluntnose minnow (*Pimephales notatus*), emerald shiner (*Notropis athernoides*), yellow perch, (*Perca flavescens*), bluegill (*Lepomis macrochirus*), and spotfin shiner (*Cyprinella spiloptera*). All of these species are indigenous to the area. The five species found at the most number of sites were the largemouth bass (*Micropterus salmoides*), bluntnose minnow, bluegill, common carp (*Cyprinus carpio*) and green sunfish (*Lepomis cyanellus*). The common carp is not a native species to the area.

The eight hybrids identified consisted primarily of crosses between the species of sunfishes (*Lepomis*) although there were two minnow combinations and a cross between the non-native white perch (*Morone americana*) and native yellow bass (*Morone mississippiensis*) (catalogue number INHS 97039).

The search of the INHS database for the entire area, including the Fox and Kankakee drainages and Dennison materials found 119 native species, 17 non-native species, and 13 hybrid combinations (Table 1). The total number of INHS records of native species, non-native species, and hybrids are, respectively, for the urban Chicago region 85, 16, and 10; for the Fox River drainage 88, 4, and 4; for the Kankakee River drainage 89, 3, and 1.

DISCUSSION

General Observations on Urban Chicago Fishes

The number of native species (119) found in the entire region is far greater than the 82 native species found by Meek and Hildebrand (1910). However, their list was general and based often on common knowledge of what was occurring in the area and not from a concerted effort to survey and voucher specimens in a collection. Indeed, their paper included 25 species that have never been known to occur in the Chicago area. Herein we report 62 native species that were not reported by Meek and Hildebrand (1910).

Despite the past problems with water pollution in the urban Chicago waterways, the area still supports a relatively diverse, although altered, fish fauna. Indeed, if all INHS records since 1990 for urban Chicago are examined, there are records for 85 native species. However, the assemblage is dominated by a few species (i.e. bluegill, green sunfish, common carp) that are generally considered to be tolerant of lower water quality and habitats (Smith, 1979). In the Dennison collections, most species are represented by few specimens. This high number of rare species strongly suggests that a high proportion of the fish fauna is at risk of extirpation from the area.

Even within the Chicago waterways, there are differences in the fish faunas among the lower Des Plaines River, Chicago canal system, and Lake Michigan. The fish community

of the lower Des Plaines drainage is in better condition in terms of the lower percentage of non-native species and hybrids than the Chicago canal system. The percent of non-native species in the Des Plaines is 10% of the total and that of the Chicago canal system is 26%. The proportion of hybrids to total number of species is 14% and 18%, respectively.

The Chicago canal system is a bit of an anomaly because the canals simply did not exist previously. The system's connection between Lake Michigan and the Illinois River system results in a mixed fauna.

The Dennison collection contained only one sample from Lake Michigan proper, which contained a fairly diverse collection of 17 species. However, the collection also had a high number of non-native species (five species; 29% of the total number of species). This number is consistent with 26 species obtained by Savitz et al. (1996) from four Chicago harbors. Other INHS Fish Collection records since 1990 indicate that 44 species occur in Lake Michigan in Cook County. Of these, 11 (25% of the total number of species) are non-native species, of which four of these are stocked salmonid species.

Also in the area, including Lake Michigan, few species considered sensitive do occur, such as the yellow perch and spotfin shiner, although in low numbers (Smith, 1979). Two species are listed as state threatened: longnose sucker (*Catostomus catostomus*) and banded killifish (*Fundulus diaphanus*). The longnose sucker is likely to occur throughout Lake Michigan but appears to rarely stray into inland waters of Illinois. The banded killifish occurs in the Wolf and Powder Horn lakes of southern Cook County. In Illinois, the killifish occurs only in one other area, the glacial lakes in Lake County (Smith, 1979, INHS collection records).

The proportion of non-native species (19%) in the urban Chicago area is very high relative to the Fox and Kankakee River drainages with 5% and 3% respectively and suggests a significantly altered fish community. The high number of hybrids also is considered to be a signal of a highly disturbed system (Karr et al., 1986); which certainly is represented by this system of fairly uniform canals and ditches. Lack of habitat diversity likely would lead to a reduction of reproductive barriers among species.

Impacts of Non-native Species

The connection now between the Lake Michigan-Atlantic Ocean and Illinois-Mississippi rivers has added an extra sense of concern with the movement of non-native species between the two systems, particularly, the occurrences of the white perch, oriental weatherfish (*Misgurnus anguillicaudatus*) and round goby (*Neogobius melanostomus*) in Chicago waterways. These are non-native species that are recent invaders to the area. The possible movement of two Asian carp species of the genus *Hypopthalmichthys* from the Illinois River to Lake Michigan is of a serious concern; however, neither of these species was found to be present in the Dennison material. Interestingly, a third Asian carp, the grass carp (*Ctenopharygodon idella*) is known to exist in Lake Michigan (INHS 59326, a Dennison specimen previously vouchered), but this single record suggests that the species remains rare in the lake, at least for the time being.

The white perch, indigenous to the Atlantic Coast of North America, arrived in Lake Ontario during the 1940s (Johnson and Evans, 1990). From there, the species spread to the other Great Lakes, arriving in Lake Michigan (including Illinois waters) during the mid- to late 1980s (Savitz et al., 1989). The species passed through the Chicago waterways into the lower Illinois River by 1991 (Irons et al., 2002) and the Mississippi River by 1993—94 (Burr et al., 1996).

The greatest concern is that the white perch will compete and hybridize with the other *Morone* species. There is evidence that the white perch eats the eggs of walleye (*Stizostedion vitreum*), white bass (*Morone chrysops*), and other fishes (Schaeffer and Margraf, 1987). Madenjian et al. (2000) demonstrated that white bass recruitment in Lake Erie declined after the invasion of white perch. Irons et al. (2002) reported hybridization between yellow bass and white perch. One sample from the Dennison collection also contained a yellow bass and white perch hybrid. Hybridization could indicate that the yellow bass gene pool is threatened by the influx of white perch genes (Irons et al., 2002).

While temperatures may limit white perch populations in parts of the Great Lakes, a study by Johnson and Evans (1990) suggests that much of Lake Michigan has temperatures suitable for the white perch. They predicted in 1990 that, coupled with the proper habitat, white perch might flourish in Lake Michigan. Records from the Dennison collection and other INHS records suggest that this prediction has proven to be true. The species now appears to have become more common than the other two native *Morone* species (yellow bass and white bass) in the urban Chicago region. Although the latter two species declined in the area before the arrival of white perch (Smith, 1979), the presence of white perch might prevent the reestablishment of the two native *Morone*. In the Dennison samples, 68 specimens of white perch were collected from 10 sites versus nine specimens from four sites for yellow bass and three specimens from two sites for white bass.

The oriental weatherfish is native to eastern Asia and has been established or collected in nine states including Illinois according to the US Geological Survey (http://nas.er.usgs.gov/queries/spCollections.asp?SpeciesID=498&State=&HUCNumber=). The species is a fairly recent invader to the area with the earliest verifiable record dating to 1987 (INHS 61129, Burr et al., 1996). At this point, these populations do not seem to be expanding (Burr et al., 1996). The Dennison materials verify their continued existence in the Chicago waterways and indicate that the population has maintained its limited geographic range. Regardless, its ability to survive in small streams suggests that it has the ability to survive in streams throughout the upper Midwest, although it might be limited to degraded small streams. Because it is a common species in the aquarium trade, populations could be expected to occur anywhere in the Midwest (Burr et al., 1996). The oriental weatherfish could become a competitor with native species, particularly darters and catfishes. They would occupy similar habitats and possibly consume the same prey items (Laird and Page, 1996).

The round goby (*Neogobius melanostomus*) is an Eurasian invader that is a native to the Black and Caspian seas (Charlebois et al., 2001). It was first found in the Great Lakes in 1990, and later spread to all of them as well as several tributaries (Charlebois et al.,

2001). The first detection of the round goby in the Chicago area appears to have been in 1994 as reported by Janssen and Jude (2001) and INHS records from Calumet Park (INHS 32982) and the Calumet River (INHS 34877). Although Laird and Page (1996) indicated that it first appeared in 1993, they provided no documentation to support this date. INHS staff in Havana, Illinois, captured one juvenile specimen in July 2004 from the Illinois River near Peoria (K. Irons pers. comm., INHS uncat.). While an electric barrier constructed at the origin of the Illinois River near Romeoville was originally designed to keep gobies out of the Illinois River, it appears that they have already established themselves in the river (D. Thomas, pers. comm.)

Likely, the species also will become established throughout the tributaries of the Illinois River. Indeed, two large adults from Flag Creek, a tributary of the Des Plaines, in the INHS collection (INHS 97590), suggest that the species will flourish in smaller streams of Illinois and the Midwest. Phillips et al. (2003) found the species has become established in four tributaries of Lake Erie and is a dominant species in at least one of the tributaries.

Competition between the round goby and native fishes is a major concern. According to a recent study, it is believed that the round goby has caused a local extinction of the mottled sculpin (*Cottus bairdi*) in the Calumet Harbor area of Lake Michigan (Janssen and Jude, 2001). This scenario may occur in many habitats throughout Lake Michigan and with other species such as darters in Illinois River tributaries.

A number of salmonid species occur in the area, particularly throughout Lake Michigan (Laird and Page, 1996). Although the brook trout (*Salvelinus fontinalis*) and lake trout (*Salvelinus namaycush*) are native to Lake Michigan, the others, coho salmon (*Oncorhynchus kisutch*), rainbow trout (*Oncorhynchus mykiss*), Chinook salmon (*Oncorhynchus tshawytscha*), and brown trout (*Salmo trutta*) are not native to the area. What differentiates these species from the other non-native species is that they are intentionally stocked in Lake Michigan, and none except perhaps the brown trout would be able to maintain self-sustaining populations in southern Lake Michigan (Smith, 1979). Given their cold-water requirements, any escape into the Illinois River system will not result in any permanent populations of non-native salmonids being established.

While the Chicago region does support a relatively high number of native species, the proportion of non-native species is high. Although efforts are beginning to control the spread of non-native species, it is unlikely that any of these species currently present will be eliminated from the area. Some of these non-native species will likely continue to have an impact on the local native fish fauna and broader aquatic community.

ACKNOWLEDGMENTS

We would like to thank Sam Dennison for his donation of specimens and many other field biologists including Kevin Irons, Gary Lutterbie, and Vic Santucci for their contributions of specimens to INHS. The Indiana-Illinois Sea Grant program provided support for the processing and inclusion of the Dennison materials into the INHS fish collection. Chris Mayer, Karyla Trester, and Frank Hutto provided database, map, and GIS exper-

tise. David Thomas and Jeremy Tiemann provided comments on the manuscript. Anna Fitzsimmons provided valuable assistance with literature in the INHS library.

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Figure 1. Map of the northeastern Illinois containing the area of study. Large bold text are county names.

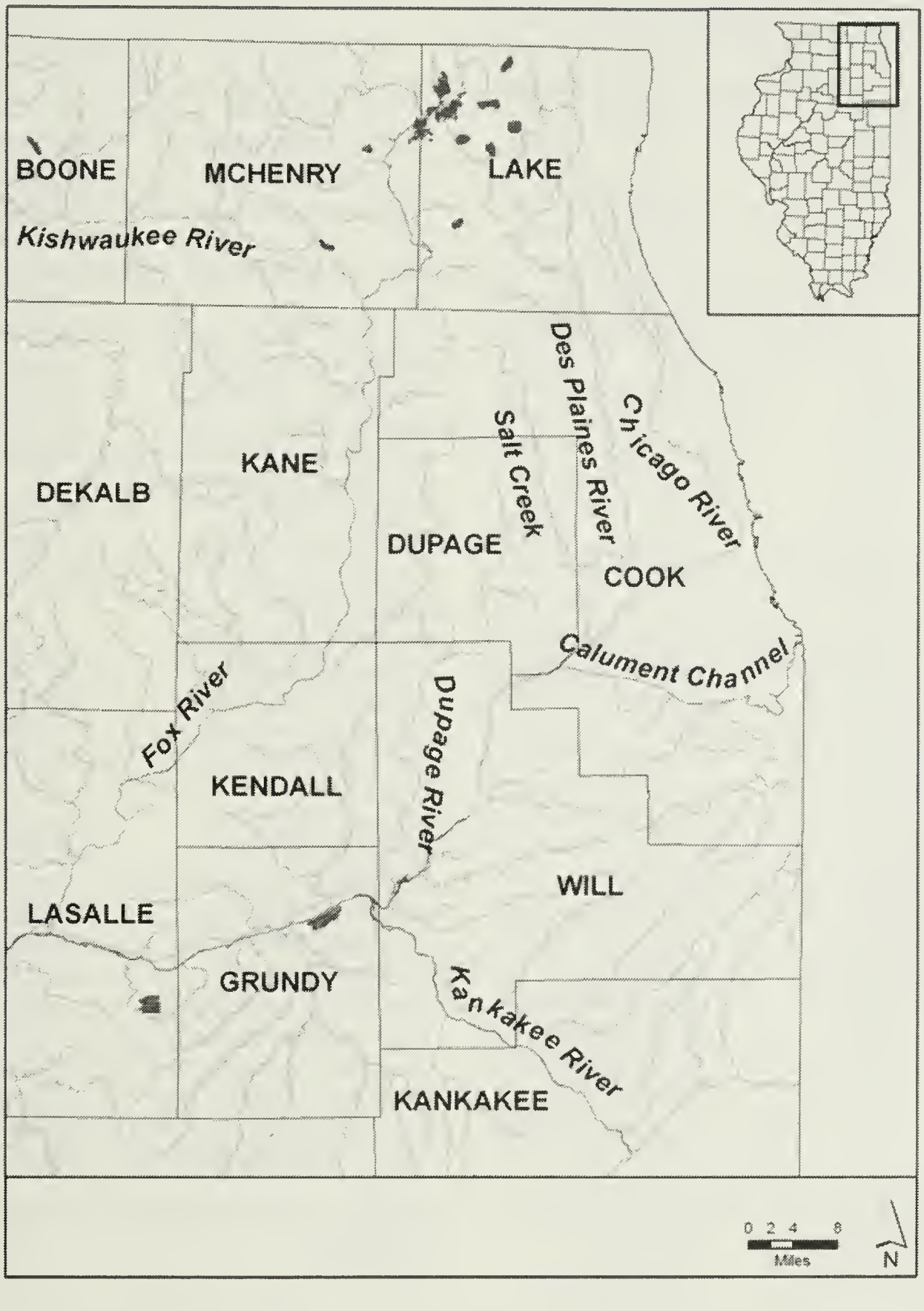

Table 1. Fishes of the Chicago, Illinois region based on vouchered INHS fish collection data. Based on materials collected after 1990. I = non-native species, A = found in part or all of area comprised of Des Plaines drainage, Chicago canal system & Lake Michigan, B = found in the Fox River drainage, C = found in the Kankakee River drainage.

Petromyzontidae	
Lampetra appendix C	American brook lamprey
Petromyzon marinus I, A	sea lamprey
Lepisosteidae	
Lepisosteus osseus A,B,C	longnose gar
Lepisosteus platostomus C	shortnose gar
Amiidae	
Amia calva A,C	bowfin
Hiodontidae	
Hiodon alosoides C	goldeye
Clupeidae	
Alosa chrysochloris A,C	skipjack herring
Alosa pseudoharengus I,A	alewife
Dorosoma cepedianum A,B,C	gizzard shad
Cyprinidae	
Campostoma anomalum A,B,C	central stoneroller
Campostoma oligolepis B	largescale stoneroller
Carassius auratus I,A	goldfish
Carassius auratus x *Cyprinus carpio* A	
Couesius plumbeus A	lake chub
Ctenopharyngodon idella I,A,B	grass carp
Cyprinella lutrensis A,C	red shiner
Cyprinella lutrensis x *C. spiloptera* A,C	
Cyprinella spiloptera A,B,C	spotfin shiner
Cyprinella whipplei B	steelcolor shiner
Cyprinus carpio I,A,B,C	common carp
Ericymba buccata C	silverjaw minnow
Hybopsis amnis C	pallid shiner
Hybognathus nuchalis B	Mississippi silvery minnow
Hypophthalmichthys nobilis I,C	bighead carp
Luxilus chrysocephalus A,B,C	striped shiner
Luxilus cornutus B	common shiner
Lythrurus umbratilis A,B,C	redfin shiner
Nocomis biguttatus A,B,C	hornyhead chub
Notemigonus crysoleucas A,B,C	golden shiner
Notropis anogenus B	pugnose shiner
Notropis atherinoides A,B,C	emerald shiner
Notropis buchanani A,C	ghost shiner
Notropis chalybaeus C	ironcolor shiner
Notropis dorsalis A,B,C	bigmouth shiner
Notropis dorsalis x *N. rubellus* B	
Notropis heterodon B	blackchin shiner
Notropis heterolepis B	blacknose shiner
Notropis hudsonius A,B	spottail shiner
Notropis ludibundus A,B,C	sand shiner
Notropis rubellus A,B,C	rosyface shiner
Notropis rubellus x *Luxilus chrysocephalus* B	
Notropis texanus C	weed shiner
Notropis volucellus B,C	mimic shiner
Opsopoeodus emiliae B,C	pugnose minnow
Phenacobius mirabilis A,B,C	suckermouth minnow
Phoxinus erythrogaster A,B,C	southern redbelly dace
Pimephales notatus A,B,C	bluntnose minnow
Pimephales promelas A,B,C	fathead minnow
Pimephales vigilax B,C	bullhead minnow
Rhinichthys atratulus B,C	blacknose dace
Rhinichthys cataractae A	longnose dace
Scardinius erythrophthalmus I,A,B	rudd
Semotilus atromaculatus A,B,C	creek chub
Catostomidae	
Carpiodes carpio A,B,C	river carpsucker
Carpiodes cyprinus A,B,C	quillback
Carpiodes velifer B	highfin carpsucker
Catostomus catostomus A	longnose sucker
Catostomus commersoni A,B,C	white sucker
Erimyzon oblongus A	creek chubsucker
Erimyzon sucetta B,C	lake chubsucker
Hypentelium nigricans A,B,C	northern hog sucker
Ictiobus bubalus A,B,C	smallmouth buffalo
Ictiobus cyprinellus A,C	bigmouth buffalo
Ictiobus niger A,C	black buffalo
Minytrema melanops A,C	spotted sucker
Moxostoma anisurum A,B,C	silver redhorse
Moxostoma carinatum B,C	river redhorse
Moxostoma duquesnei B,C	black redhorse
Moxostoma erythrurum A,B,C	golden redhorse
Moxostoma macrolepidotum A,B,C	shorthead redhorse
Moxostoma valenciennesi B	greater redhorse
Cobitidae	
Misgurnus anguillicaudatus I,A	Oriental weatherfish
Ictaluridae	
Ameiurus melas A,B,C	black bullhead
Ameiurus natalis A,B,C	yellow bullhead
Ameiurus nebulosus C	brown bullhead
Ictalurus punctatus A,B,C	channel catfish
Noturus exilis A,B,C	slender madtom
Noturus flavus A,B,C	stonecat
Noturus gyrinus A,B,C	tadpole madtom
Pylodictus olivaris B,C	flahead catfish
Esocidae	
Esox americanus A,B,C	grass pickerel
Esox lucius A,B,C	northern pike
Esox lucius x *E. masquinongy* A	tiger muskie

Esox masquinogy B muskie
Umbridae
Umbra limi A,B,C central mudminnow
Salmonidae
Coregonus clupeaformis A lake whitefish
Coregonus hoyi A bloater
Oncorhynchus kisutch I,A coho salmon
Oncorhynchus mykiss I.A rainbow trout
Oncorhynchus tshawytscha I,A chinook salmon
Prosopium cylindraceum A round whitefish
Salmo trutta I,A brown trout
Salvelinus namaycush A lake trout
Percopsidae
Percopsis omiscomaycus A,C trout-perch
Aphredoderidae
Aphredoderus sayanus C pirate perch
Gadidae
Lota lota A burbot
Atherinidae
Labidesthes sicculus A,B,C brook silverside
Fundulidae
Fundulus diaphanus A,B banded killifish
Fundulus dispar B,C starhead topminnow
Fundulus notatus A,B,C blackstripe topminnow
Poeciliidae
Gambusia affinis A,B,C mosquitofish
Poecilia latipinna I,A sailfin molly
Gasterosteidae
Culaea inconstans A,B brook stickleback
Gasterosteus aculeatus I,A threespine stickleback
Pungitius pungitius A ninespine stickleback
Cottidae
Cottus bairdi A,B,C mottled sculpin
Cottus cognatus A slimy sculpin
Myoxocephalus thompsoni A deepwater sculpin
Moronidae
Morone americana I,A,C white perch
Morone americana x *M. mississippiensis* A
Morone chrysops A,B,C white bass
Morone chrysops x *M. saxatilis* A
Morone mississippiensis A,B yellow bass

Centrarchidae
Ambloplites rupestris A,B,C rock bass
Lepomis cyanellus A,B,C green sunfish
Lepomis cyanellus x *L. gibbosus* A,B
Lepomis cyanellus x *L. humilis* A
Lepomis gibbosus A,B,C pumpkinseed
Lepomis gibbosus x *L. macrochirus* A
Lepomis gibbosus x *L. megalotis* A
Lepomis gulosus A,B,C warmouth
Lepomis humilis A,B,C orangespotted sunfish
Lepomis humilis x *L. macrochirus* A
Leponis macrochirus A,B,C bluegill
Lepomis megalotis A,C longear sunfish
Lepomis microlophus I,B redear sunfish
Micropterus dolomieu A,B,C smallmouth bass
Micropterus dolomieu x *M. salmoides* B
Micropterus punctulatus I,A spotted bass
Micropterus salmoides A,C largemouth bass
Pomoxis annularis A,B,C white crappie
Pomoxis nigromaculatus A,B,C black crappie
Percidae
Ammocrypta clara C western sand darter
Etheostoma asprigene B mud darter
Etheostoma caeruleum B,C rainbow darter
Etheostoma chlorosomum B,C bluntnose darter
Etheostoma exile A,B Iowa darter
Etheostoma flabellare A,B,C fantail darter
Etheostoma gracile B slough darter
Etheostoma microperca A,B,C least darter
Etheostoma nigrum A,B,C johnny darter
Etheostoma spectabile A,B,C orangethroat darter
Etheostoma zonale B,C banded darter
Perca flavescens A,B yellow perch
Percina caprodes A,B,C logperch
Percina maculata A,B,C blackside darter
Percina phoxocephala A,B,C slenderhead darter
Sander vitreus A,B,C walleye
Sciaenidae
Aplodinotus grunniens A,B,C freshwater drum
Gobiidae
Neogobius melanostomus I,A round goby

Transactions of the Illinois State Academy of Science
(2005), Volume 98, #1&2, pp. 75-80

received 10/11/04
accepted 3/13/05

New Distributional Records for Illinois Crayfishes (Decapoda: Cambaridae) with Comments on the Continued Spread of Non-native Species

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ABSTRACT

Recent sampling has provided new records for two Illinois crayfish species that dramatically increase their known ranges within the state. The new records for the cajun dwarf crayfish, *Cambarellus shufeldtii*, most likely represent an undiscovered population while those of the red swamp crawfish, *Procambarus clarkii*, represent an introduced population. The records of the latter species illustrate the continual problem of non-native species introductions and the lack of effective regulatory mechanisms.

INTRODUCTION

In addition to providing information for biogeographic analyses, current distributional data for organisms provide the foundation for sound conservation and management decisions. Current data are especially pertinent to the regulation and importation of non-native aquatic species. Once established, non-native aquatic species such as crayfishes are difficult, if not impossible, to eradicate. The threat from non-native crayfishes is more ominous given their ability to displace native crayfishes and diminish ecosystem integrity (Lodge, et al., 2000). The prompt reporting of non-native species' range expansions can be beneficial to various state and provincial natural resource agencies as they grapple with and debate methods to prevent the establishment of such species.

Recent fieldwork by Illinois Department of Natural Resources biologists has resulted in the collection of two crayfish species well outside of their previously known ranges

within Illinois. These two cambarid species, and possible explanations for their range expansions, are discussed in detail below.

Cambarellus shufeldtii

As the vernacular name implies, the Cajun dwarf crayfish, *Cambarellus shufeldtii*, is a small crayfish found natively in the Gulf Coastal Plain of the United States. The species is usually brownish in overall color and has two lengthwise stripes or rows of spots along its dorsum; adult size rarely exceeds 3.3 cm (Page, 1985; Taylor and Schuster, 2004). *Cambarellus shufeldtii* is found in numerous types of shallow lentic habitats including cypress swamps, sloughs, backwaters, and ditches (Penn, 1950; Page, 1985). The species occurs in the Gulf Coastal Plain from east-central Missouri south to the coasts of Texas and Louisiana (Hobbs, 1989; Pflieger, 1996). In Illinois Page (1985) reported the species only from extreme southern Illinois in Alexander, Jackson, Massac, Pulaski, and Union Counties.

On 6 June 2003 three female individuals of *C. shufeldtii* were collected from near a boat ramp at the northern end of Stump Lake (39° 1.12'N, -90° 33.88'W), Jersey County, Illinois. Thirty-eight specimens were again collected from the same site on 18 March 2004. Both collections are vouchered in the INHS Crustacean Collection as INHS 9309 and INHS 9307, respectively. Stump Lake is a complex of backwater floodplain lakes of the Illinois River and is located approximately 13 km upstream of the Illinois' confluence with the Mississippi River (Fig. 1). These collections expand the known range of the species in Illinois by over 185 km to the north.

The collection of *C. shufeldtii* from Stump Lake is not surprising given that Pflieger (1996) reported the species from Mississippi River floodplain lakes in Lincoln County, Missouri. Lincoln County occurs at the same latitude as Jersey County, Illinois and is separated from Stump Lake only by the Mississippi River and an approximately 90-95 m high north to south ridge which forms the drainage divide between the Mississippi and Illinois Rivers. The floodplain habitats favored by *C. shufeldtii* occur commonly along the lower Illinois River and to a lesser extent along the Mississippi River from St. Louis to Cairo, Illinois. These habitat types can be difficult to sample using traditional techniques and this may explain the absence of previous collections of *C. shufeldtii* in the Illinois River drainage. Undoubtedly, more collections of the species along the lower Mississippi and Illinois rivers in Illinois will occur.

Procambarus clarkii

The red swamp crawfish, *Procambarus clarkii*, is one of North America's largest and most economically important species. The large brick red adults of the species frequently exceed 13 cm in total length. *Procambarus clarkii* is commonly consumed by humans in the southern United States and is marketed as a delicacy in other regions of the country and world. Total annual harvest from native and pond–cultivated populations in the United States average between 30,000 and 40,000 metric tons (Huner, 2002). The preferred habitat of *Procambarus clarkii* in its native range is swamps, vegetated ponds, seasonally flooded ditches, and shallow lowland creeks. However, introduced populations of the species have shown a propensity to successfully colonize large lakes and higher gradient creeks and rivers. *Procambarus clarkii* occurs natively in the Gulf Coastal Plain from extreme southern Illinois south and west to northeastern Mexico and east to the

Florida panhandle (Hobbs, 1989). The species has been widely introduced in North America, Europe, Asia, and Africa. In the United States established non–native populations now occur in California, Nevada, Idaho, New York, North Carolina, Ohio, Oregon, and Washington (Taylor and Schuster, 2004). In Illinois the species was formerly known only from lowland habitats in the extreme southern Illinois counties of Alexander, Jackson, Massac, Pope, Pulaski, and Union (Page, 1985) (Fig. 2).

While conducting fish surveys, Illinois Department of Natural Resources biologists collected four adult (one male, three female) *Procambarus clarkii* from the North Branch of the Chicago River at River Park, just downstream of Foster Avenue in Chicago (41° 58.40'N, -87° 42.26'W), Cook County, Illinois on 31 July 2001 (Fig. 2). On a return visit to the same site on 1 September 2004 the first author collected three adult *P. clarkii* and one juvenile. Both collections are vouchered into the INHS Crustacean Collection as INHS 8909 and 9478, respectively. At another site, one adult and one juvenile *P. clarkii* were collected from the same body of water approximately 2.5 km downstream of the River Park site on the same date (INHS 9479). The collection of both adult and juvenile individuals from multiple sites and three-year time lapse between collections at the River Park site indicates that *P. clarkii* is reproducing and now successfully established in the North Branch of the Chicago River.

The establishment of *P. clarkii* in extreme northeastern Illinois is significant in that it illustrates the species' plasticity to climates. The northern limit of the species' native range is extreme southern Illinois where average ambient January air temperature is 0.12 C (32.2°F), whereas average January temperature in Chicago, IL is –5.1 C (22.8°F) (http://www.giss.nasa.gov/data/update/gistemp/station_data). Assuming that lower ambient air temperatures correlate with lower surface water temperatures, the extreme northeastern Illinois climate represents the coldest known temperature at which the species is known to survive. While populations of *P. clarkii* are established in the environs of Zurich, Switzerland and Hamburg, Germany, January temperatures for those regions still average 10.0 to 11.0°F higher than Chicago, IL.

The ability of *P. clarkii* to successfully colonize new habitats after its introduction has been attributed to several of the species' life history traits including its ability to burrow, resistance to air exposure, polytrophism, rapid growth, high fecundity, and disease resistance (Lindqvist and Huner, 1999). A wider tolerance to climate variables such as temperature can now be added to that list. Climate has been suggested as a barrier to the expansion of non-native crayfishes (Lindqvist and Huner, 1999). The example of *P. clarkii* clearly demonstrates that that contention should be re-evaluated, especially by regulatory agencies that review aquaculture permit applications for crayfishes.

The pathway of introduction for the North Branch Chicago River population of *P. clarkii* is unknown. The two most likely are the release of aquarium pets or release of unused fishing bait. Both the pet and bait industry are at best loosely regulated. In Illinois it is illegal to possess live rusty crayfish, *Orconectes rusticus*, because of that species' known dispersal and displacement abilities. However, by not issuing a blanket ban on the possession of any live crayfish as bait, as was done in Wisconsin, Illinois and other states will continue to be vulnerable to introductions of other non-native species.

ACKNOWLEDGMENTS

We thank T. G. Anton and J. T. Lamer for field assistance and F. Hutto for assistance with figures.

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Figure 1. Distribution of *Cambarellus shufeldtii* in Illinois with inset indicating global native range in North America. Black star indicates newly discovered Jersey County population, black circles indicate all previously known records for species in the state.

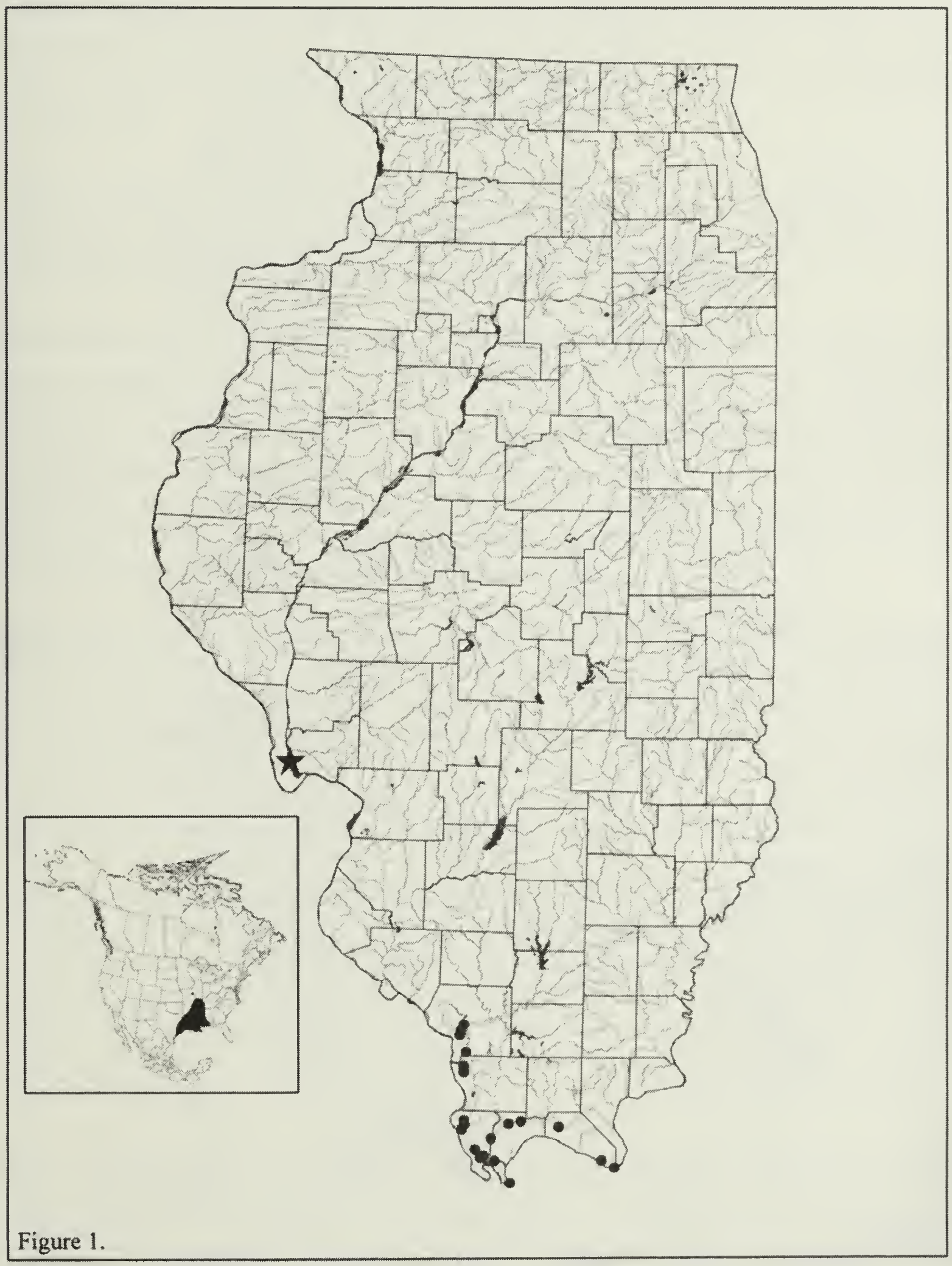

Figure 1.

Figure 2. Distribution of *Procambarus clarkii* in Illinois with inset indicating global native range in North America. Black star indicates newly discovered Cook County population, black circles indicate all previously known records for species in state.

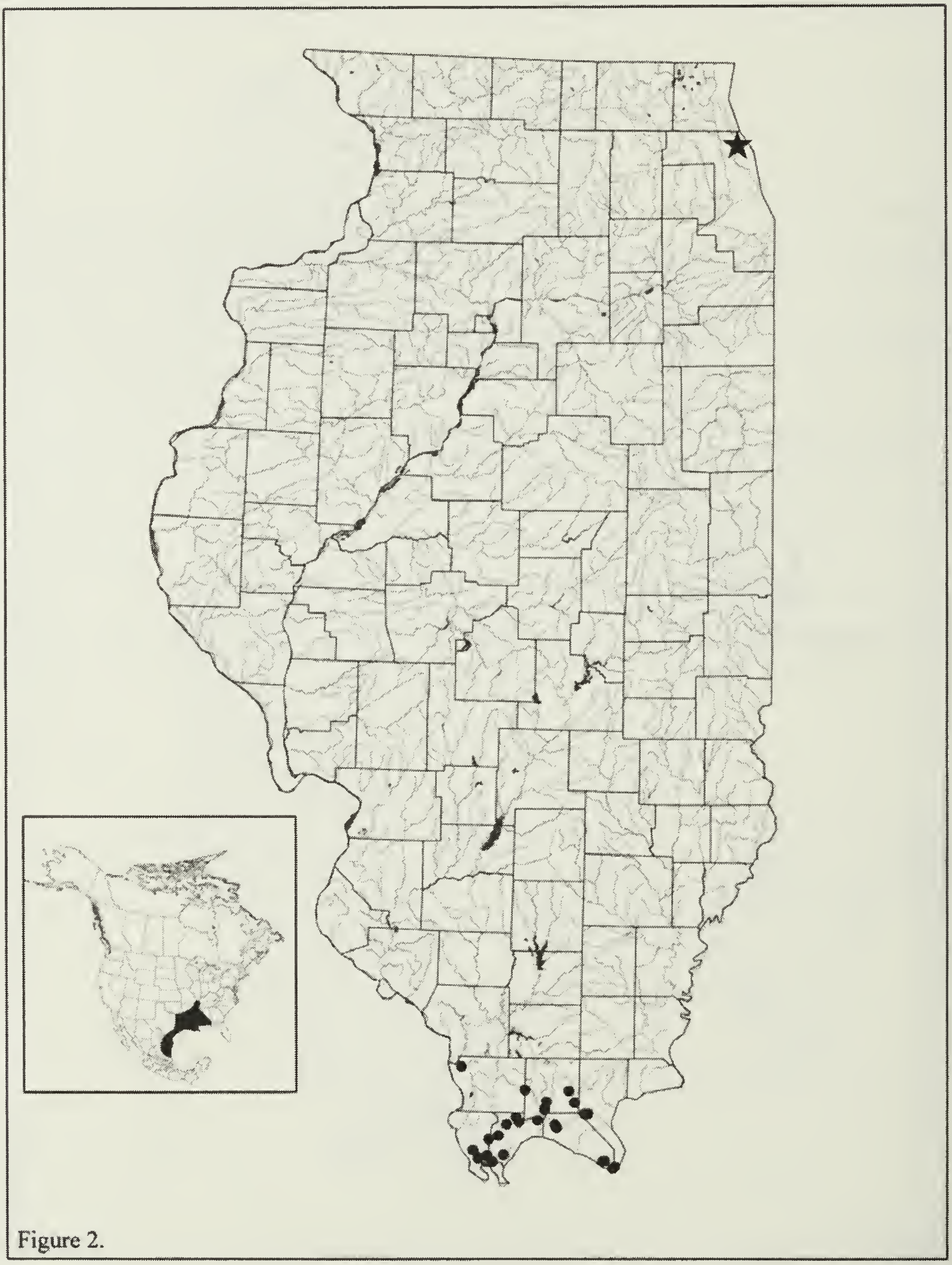

Figure 2.

BOOK REVIEW 2005 - #1

Mohlenbrock, Robert H. Sedges: *Cyperus* to *Scleria*. Second Edition. 2001. xviii + 223 pages; introduction; dichotomous keys; descriptions; illustrations; distribution maps; appendix with additions and changes to the first addition, numerical summary of taxa, glossary, literature cited; index of plant names. Southern Illinois University Press, Carbondale and Edwardsville, Illinois. Hard Cover. Price: US $45.00. ISBN 0-8093-2358-3. Available from Southern Illinois University Press, P.O. Box 3697, Carbondale, IL 62902-3697.

Sedges: *Cyperus* to *Scleria* is a companion volume to Sedges: *Carex* published in 1999 and reviewed here in 2000 (Volume 93, Number 1). Both volumes are parts of the Illustrated Flora of Illinois series for which Mohlenbrock is the general editor and author of the twelve important and appreciated volumes on the vascular plants.

The format of this edition is the same as the first edition (1976) and its contents are the same for pages 1-178. For those unfamiliar with the first edition the "Introduction" (pages 1-14) includes information on the critical morphological features of sedges with clear illustrations, a discussion on the occurrences of selected Illinois sedges with respect to their habitats ranging from wetlands to relatively dry woodlands, and an illustrated dichotomous key to 13 genera of sedges (Cyperaceae). The genera covered in this key are *Bulbostylis, Carex, Cladium, Cyperus, Dulichium, Eleocharis, Eriophorum, Fimbristylis, Fuirena, Lipocarpha, Rhynchospora, Scirpus,* and *Scleria.*

Subsequent to the generic key is the taxonomic treatment of the sedge species, except for species of *Carex*, under the heading "Descriptions and Illustrations" (pages 15-178). In this portion of the manual, morphological features of each genus are discussed followed by a dichotomous key to its species. Next the species of the genus are treated in the order in which they appear in the key. Species descriptions include information on nomenclature, habitats, ranges, and state distributions by counties shown on dot maps. Furthermore, each species description is accompanied by a noteworthy illustration.

Hence, the major new feature of the second edition is the appendix entitled "Additions and Changes to the First Edition." The contents of the appendix (pages 181-210) includes the addition of six species of sedges to our Illinois flora, nomenclatural revisions for selected taxa and numerous taxa listed with additional county records for their respective state distribution dot maps found on pages 15-178. Also, the author comments about the exclusion of *Rhynchospora macrostachya* from our flora; and accordingly it should be deleted on page 159.

The six sedges added to our flora are *Cyperus retrorsus, Cyperus* X *mesochorus, Eleocharis macrostachya*, *Schoenoplectus californicus*, *S. deltarum*, and *S. mucronatus*. These species are treated with respect to descriptions and illustrations as were the species on pages 15-178. Although there are no state distribution dot maps for these six species, the counties are listed in which they have been documented by specimens.

The author has revised *Cyperus* and *Scirpus* to now include segregate genera; and thus nomenclatural changes were made for several taxa. One species of *Cyperus* is now in the segregate genus *Kyllinga* (pages 181 and 183). Also, seventeen taxa of *Scirpus* are now placed among five segregate genera (pages 197-209); that is, two species in *Bolboschoenus,* two species in *Hemicarpha,* one species in *Isolepis,* eight species and two forms in *Schoenoplectus* (not including the three additional species mentioned previously) and two species in *Trichophorum.* Because of these changes, nomenclatural changes of other taxa and additions to our flora, the author has revised the dichotomous key to the species of *Cyperus* and constructed a key to the species in the six genera of the *Scirpus* complex. Also, a new key to the species of *Eleocharis* is provided.

Following the appendix, the numerical summary of the taxa covered in the entire second edition reports 18 genera, 91 species, 6 varieties and 3 [4] forms compared to 12, 85, 7 and 3 taxa in the first edition, respectively. A useful glossary follows and then the literature cited that includes several new citations. The manual ends with a combined index of Latin and common plant names alphabetically arranged. Accepted Latin names and their synonyms are listed, but distinguished by roman and italic print styles, respectively.

Users of this edition need to remember that the first 178 pages, from the first edition, were not edited for nomenclatural and distributional changes. Therefore, users must check the appendix for possible changes. For example, the introduction on page 8 referring to remnant prairies in Illinois (paragraph 5), reads: "Relatively moist prairies provide suitable habitats for *Eleocharis elliptica* var. *compressa*, *Carex interior*, *C. buxbaumii*, and *C. conoidea*." Here the author now considers this variety of *Eleocharis* to be a distinct species, *E. compressa* (page 196). Also, the users will need to go to page 84, where *E. elliptica* var. *compressa* is treated, to note the nomenclatural changes and add Union county to its state distribution dot map. Furthermore, the handy illustrated dichotomous key to the genera of sedges on pages 11-14 was not revised to incorporate the segregate genera mentioned previously. In using this key, users will especially need to refer to the *Scirpus* complex key in the appendix.

Nevertheless, Mohlenbrock's contributions to our knowledge of Illinois' vascular flora are remarkable. The idea of producing manuals of our flora, in which every species is described and illustrated, is an exceptional endeavor. To this end, Mohlenbrock has made significant achievements for his area of expertise, the vascular plants. All students and investigators working on the sedges of Illinois and surrounding states will need this volume.

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BOOK REVIEW 2005 - #2

Burger, William C. Perfect Planet, Clever Species: How Unique Are We? 2003. 345 pages; introduction; 11 chapters; 2 figures; 12 colored photographs; notes (comments and literature citations); index. Prometheus Books, Amherst, New York. ISBN 1-59102-016-6. Hard Cover. Price: US $29.00. Available from Prometheus Books, 59 John Glenn Drive, Amherst, New York 14228-2197.

William C. Burger, Curator Emeritus of Botany at the Field Museum of Natural History (Chicago, Illinois), has skillfully brought together a vast amount of information, from several disciplines, into a coherent exploration of evolution. This study reveals the circumstances that surrounded the origins and development of our galaxy, solar system, and planet; that in turn created the circumstances that fostered the origins and evolution of living things, on Earth, with a focus on humankind's long journey to where we are today.

Apparently, the impetus for this evolutionary history centered around the question "How Unique Are We?" with respect to the ongoing concerns, at least in some quarters, about the possibility of life, especially intelligent life, elsewhere in the universe and maybe in other universes as well. The author builds a step by step case leading to the conclusion that we (intelligent beings) are probably alone in the universe. Even for our planet, Burger writes in Chapter 11 (p. 290): "However unlikely our odyssey, the incontrovertible fact is that our planet, our solar system, and our star are ideally configured for the development of intelligent life here on Earth."

Burger's multi-disciplinary narrative in only eleven chapters is a read of fascinating details, engaging questions, thoughtful insights, and subtle humor. In addition, there are other features of the book that contribute to its distinctiveness. Each chapter begins with captivating introductory comments; for example opening sentences in Chapter 5 (p. 111) read: "Creatures that can contemplate the heavens, construct theories, and build instruments to scan the deep cosmos are likely to evolve only on a planet rich in biological diversity. That's what happened here on Earth. Plant and animal diversity in the woodlands and savannas of Africa sustained the emergence of humankind." Also, each chapter, except Chapter 11 (p. 192) ends with a summary characterized by effective transitional prose. For example the closing sentences of the summary for Chapter 7 (p. 192) read: "Without this increase in brain power, our planet would not now be the home of a species pondering the cosmos. Let us next look more closely at the various selective forces that may have contributed to so rapid and so costly an escalation of human intelligence." In addition, the flow of the text is not interrupted by lengthy literature references, which would be required if, for example, the author-year method were used. But the text is referenced, by superscript Arabic numerals, to additional comments by the author and a wealth of literature in the section of the book designated "Notes" (pp. 295-328). The introduction and each chapter has its own set of numerical entries in this section. There are a total of 419 entries that vary from two entries for the introduction to 83 for Chapter 8. All but a few entries have at least one literature citation and because of the numerical reference method used, some literature citations by necessity are repeated. But seemingly this redundancy is a small percent of the rich documentation. The entries in the "Notes" section are informative and I suggest that they be examined after reading

each chapter. Going from the reference number in the text to its location in the "Notes" section is user friendly, but going in the opposite direction is less so.

Because this tome covers such a broad scope of subject matter and some areas of study rely on non-experimental observations, different views have emerged on numerous topics of which some have remained controversial. Examples might include such concepts as extraterrestrial intelligent life, rate of evolution, and selection for bigger brains. Although the author may promote one view over another, he fairly presents both sides of significant issues either in the text or in the "Notes."

Burger has made an important contribution to our knowledge of natural history that will be of interest to a large body of scholars, especially those in the sciences. Furthermore, I recommend that it be adopted for a capstone college course for science majors. I believe our students need an opportunity to study, critically discuss, and write about the wide range of topics treated in Burger's Perfect Planet, Clever Species: How Unique Are We? Hence, a listing of the book's topics (chapter titles and subheadings) follows:

1. No Ordinary Star – Location, location, location; Exploded stardust; A very special star; Other stars, other planets; A very special solar system; and The Goldilocks orbit.
2. A Really Good Planet Is Hard To Find – Water, the medium for life; Carbon, the essential structural element; The right distance, the right size, the right spin; Our moon, more than just a pretty face; Venus, a very different planet; Earth's continents: stable or mobile? Geomagnetic reversals; The wet, blue and white planet; and A thin atmospheric blanket.
3. The First 4,000 Million Years – In the beginning; Life: order out of chaos; The earliest evidence of life; The nucleated (eukaryotic) cell; Creating the complex cell; The hereditary information; Deep similarities in the genetic code; Why sex? Alleles: different forms of the same gene; and Life: from outer space – or by intelligent design?
4. Life Explodes: The Last 560 Million Years – The origin of complex animals; Building a complex animal; What ignited the Cambrian explosion? Major extinctions: chapter endings in the history of life; The asteroid (Bolide) hypothesis; The evolution of a land flora; Why live on land? and Land plants diversify.
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8. Building The World's Best Brain – The *Homo erectus* stage; The Neanderthal people; Modern "Gracile" humans; Out of Africa, twice; One species or several? Ice

age climate as a cause of brain expansion; Other scenarios for brain expansion; Why humans got so smart; and Intergroup warfare as selective force.

9. An Appetite For Energy: Revolutions In Living – Human-mediated extinctions; A division of labor: two very different sexes; Gender and variance; The agricultural revolution; Plant and animal domestication; The rise of city-states; Learning to work with metals; and A growing thirst for power.
10. The Origins Of Western Science – Cadavers and the origins of western science; Voyages of discovery; Paper and printing; The scientific revolution; and A legal transformation in European society.
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Reviewers: James R. Rastorfer, Department of Biological Sciences, Chicago State University, 9501 South King Drive, Chicago, Illinois 60628 and Judith B. Rastorfer, 547 Lakewood Boulevard, Park Forest, IL 60466

BOOK REVIEW 2005 - #3

Kurz, Don. Illinois Wildflowers. 2004. 256 pages; colored photographs; descriptions; selected references; index to Latin and common plant names. Cloudland.net Publishing, Cave Mountain, Arkansas. Soft Cover. ISBN 1-882906-53-5. Price: US $22.95. Available from: Tim Ernst, Cloudland.net, HC 33, Box 50-A, Pettigrew, AR 72752.

Yatskievych, Kay. Field Guide to Indiana Wildflowers. 2000. xxxii + 357 pages; glossary; flower finder; line drawings; colored photographs; descriptions, selected references; index to Latin and common names. Indiana University Press, Bloomington, Indiana. Soft Cover. ISBN 0-253-21420-3. Price: US $17.95. Available from: Indiana University Press, 601 North Morton Street, Bloomington, IN 47404.

Nature enthusiasts in Illinois have a fine new guide to our state's wildflowers. Illinois Wildflowers by Don Kurz combines fine color photos, short descriptions, habitat/range, flowering times, and abbreviated remarks in a handy 256-page volume. Carefully framed and very informative, the plant portraits are of exceptionally high visual quality. The overall excellence of the photographs is important, since they are the means by which the reader can identify the species. Lacking keys to families, genera, or species, the species are identifiable by being arranged according to flower color and time of flowering.

The color groupings begin with white, continue with yellow, red/orange, pink, blue/purple, green, and end with brown. They are easily found thanks to color patches along the right-hand margin of the book. With this arrangement, and the large size of the color images (two per page), identification is quick and enjoyable. But just as a color-coded guide has its advantages in ease of use, there are a few disadvantages. Some flowers vary in color and these will have to be searched over a wider spectrum. Around the Chicago area the most common teasel (*Dipsacus laciniatus*) has white flowers, while the species illustrated in this book has pink flowers. But with such a distinctive inflorescence, and such a fine image, the reader should be able to identify this noxious invader without much difficulty. Another problem is that some flowers which I think of as pink, are here placed in the blue/purple category. These include wild bergamot, wild petunia and a few of the asters. But again, all one has to do is to extend one's searching and the proper match should be forthcoming. Common names are included, and formerly used scientific names are mentioned in the remarks. All can be found in the index.

This handsome little (6" X 9") volume covers 400 illustrated species, while the remarks discuss an additional 127 related species. An added feature is that the remarks often include uses by native Americans and early settlers. The author-photographer surveyed the entire state and has been employed in environmental and conservation activities for more than thirty years. Consequently, his remarks about habitat and other aspects of each species are based on many years of experience. Clearly, this is a very successful volume for the beginning botanist. You do not have to recognize plant families, crawl through complex dichotomous keys, or be familiar with the technical jargon of plant descriptions to use and enjoy this book. Also of great utility to Illinois naturalists is a similar wildflower book for Indiana.

The Field Guide to Indiana Wildflowers by Kay Yatskievych covers an awesome 1,564 species, in a slightly smaller (5.5" X 8.5") volume, that provides the reader with 640 small color photos in 357 pages. This volume begins by grouping flowers by the number of their colorful petals, followed by small outlines of 142 flower-types, in order to help you find the species you are trying to identify. The species, however, are arranged by families in a sequence only knowledgeable botanists will recognize. In short, species descriptions are usually accompanied by color images or simple line drawings. The difference in this volume is that you really should be acquainted with most of the plant families in order to use this guide efficiently. Unlike Illinois Wildflowers, the Indiana guide will be difficult for beginners (Neither book deals with woody flowering plants, nor with those herbaceous flowering plants that have little inconspicuous florets: the grasses, sedges and rushes).

All told, Illinois naturalists now have two fine, authoritative and colorful guides for identifying wildflowers in our state. The Indiana volume covers a great majority of the species found in Illinois, but it is more technical and requires some prior botanical knowledge. In contrast, the newly published Illinois Wildflowers, with large and friendly photographs, is a handsome introduction for beginners. And unlike some other recent field guides, Kurz's photographs do not display exaggerated colors, though a few have been printed rather dark. The other advantage of both volumes is that they treat our adjacent midwestern states and do not include species that only grow elsewhere, making identification much easier. Everyone interested in our state flora will benefit from these fine volumes, and every public library in Illinois would do well to have both on their shelves. Furthermore, the two volumes will be especially valuable to those instructing beginners in their local floras and all those working with volunteers in developing plant inventories. In addition, both volumes include short listings of other useful references.

Reviewer: William Burger, Curator Emeritus, Department of Botany, The Field Museum, 1400 South Lake Shore Drive, Chicago, IL 60605 and President of the Nature Camera Club of Chicago

BOOK REVIEW 2005 - #4

Kleen, Vernon M., Liane Cordle, and Robert A. Montgomery. The Illinois Breeding Bird Atlas. 2004. xviii + 459 pp; black and white species photographs; 16 figures; 12 tables; 11 appendices; literature cited; index of common names. Illinois Natural History Survey Special Publication 26. Soft Cover. ISBN 1-882932-07-2. Price: US $25.95. Available from Illinois Natural History Survey, 607 East Peabody Drive, Champaign, IL 61820.

DeVore, Sheryl, Steven D. Bailey, and Gregory Kennedy. Birds of Illinois. 2004. 376 pp; color species illustrations; appendix; select [selected] references; glossary; checklist; index of scientific names; index of common names. Lone Pine Publishing, Auburn, Washington. Soft Cover. ISBN 1-55105-379-9. Price: US $19.95. Available from Lone Pine Publishing, 1808 B Street NW, Suite 140, Auburn, WA 98001.

The publication of both The Illinois Breeding Bird Atlas (hereafter referred to as the Atlas) and the Birds of Illinois has made 2004 a benchmark year for birders at all levels. Because each book has a different purpose and special features, one may appeal more to a somewhat different audience than the other; each book is considered separately and then together to help explain this assertion.

The "Preface" to the Atlas by the noted ornithologist Dr. Scott K. Robinson presents an only slightly optimistic future for many of Illinois' bird populations. Next, a lengthy "Acknowledgments," lists all individuals who contributed to the Illinois Breeding Bird Atlas Project which resulted in this publication, that is organized as a standard scientific monograph. Subsequently, the brief "Introduction," with a clear goal statement ("...to conduct a comprehensive and systematic statewide survey of breeding birds to document their distribution and status in the state...") and a list of eight objectives, is followed by chapters entitled "Methods" and "Results and Discussion." The latter attempts, within the space of merely six pages, to make sense of all the data of the Illinois Breeding Bird Atlas Project, which was collected from 1986 to 1991 by 945 individuals, from 1,286 10-square-mile blocks spread across the entire state; this herculean effort generated 74,288 species records from 216 species.

This quite voluminous database is summarized in a series of tables and appendices of the Atlas, some of which are rather lengthy. While having access to the actual numbers may be important for archival purposes, searching large tables of numbers for patterns and trends can be daunting. At the same time, the explanatory text does point out highlights of the tables, which are sometimes obvious. For example, in Table 4 (page 7), a list of 22 species is shown in rank order by the number of priority blocks in which the species occurred; the authors explain that "The five most frequently reported species were the Red-winged Blackbird, American Robin, Mourning Dove, House Sparrow, and Common Grackle;" that is, the first five species listed in the table. It is here, in the presentation of data summaries, that the authors might have effectively used more computer graphics and thus, designed interesting and creatively organized figures where broad patterns might be easily discerned by the reader at a careful glance.

The data collected during the Illinois Breeding Bird Atlas Project published in the Atlas provides a baseline for comparison with future similar studies. Furthermore, Kleen, Cordle, and Montgomery have gone beyond simply the presentation of information relating to the Illinois Breeding Bird Atlas Project by including long-term information from the North American Breeding Bird Survey (BBS); this helps place the Atlas within a temporal context. The BBS methods and data summary, with BBS data collected throughout Illinois along standardized routes from 1966 through 2000, are presented in a special chapter of the Atlas. Here data from 133 species are grouped within a table by breeding habitat guild (woodland, grassland, etc.) and population trend (i.e., positive or negative). A further analysis considers migration status. But the authors offer only limited discussion of the data presented in these tables.

Seven land cover maps (e.g., forest cover, natural divisions) are briefly discussed in a chapter entitled "Physical Environment of Illinois." The purpose of presenting this information was to provide a background by which to interpret patterns in the data summaries. Although such analyses are mostly left up to the reader, with numerous caveats given concerning the limitations of the data, it is convenient to have these maps (which have appeared elsewhere in various publications) available in one place for easy reference.

The bulk of the Atlas is, of course, the 183 individual species accounts. Each species account includes a black and white photograph and a full map of Illinois, with county outlines, showing locations of sampling blocks for which the highlighted species was recorded as a breeder (marked: confirmed, probable, or possible). Also, each species account provides basic notations on its population status and breeding biology, as well as historical information and a variety of interesting facts. A chapter entitled "Guide to Species Accounts" helps facilitate ease of interpreting the descriptive information.

For species where sufficient data are available, the BBS trends from 1966 to 2000 are shown graphically as statewide annual indices of abundance. Because of the wide latitudinal range of Illinois and the fact that certain species distributions have changed over time, it would have been useful here to divide the state into northern, central, and southern regions (a convention established in earlier studies [e.g., Graber et al. 1970]) to show the annual indices of abundance for each region. In addition, presenting BBS trend data for Illinois' natural divisions (Schwegman 1973) could have highlighted relationships between population trends and habitat preferences, much like Jacobs and Wilson (1997) showed for BBS data in relation to Missouri's natural divisions.

Where the Atlas might cause readers to think of more in-depth data analyses that could have been presented; in contrast, the Birds of Illinois takes the reader in the opposite direction – toward the aesthetic appreciation of birds. The first impression one gets, before ever turning a page of the book, is that of an exceedingly colorful field guide. But the liberal use of color is the basis of a highly effective quick reference system to the major bird groups illustrated in the book. The reader then searches for color matches, which are readily seen, rather than thumbing through numerous pages. And because unidentified birds in the field are notorious for quickly flying out of view, the sooner one is on the proper page of the field guide, the better.

The Birds of Illinois begins with a short introductory chapter which defines some of the unavoidable technical terminology used throughout the book as well as concepts and activities associated with watching birds (e.g., composing lists and observing/recording feeding habits). DeVore, Bailey, and Kennedy suggest studying behavior, conservation issues, and bird-habitat relationships to enhance bird watching.

When discussing bird habitats, they refer to a colored map which shows the 14 natural divisions of Illinois, which for some reason they refer to as "bioregions." This map is also used to locate 100 of the top birding sites in the state, 20 of which are given a more extended treatment with information on location, bird habitats, and bird species to be expected, especially rarities. Here better directions and special information for visitors may have been better emphasized rather than attempting to list a few commonly expected birds or rarities which one may have a very small chance to see; for example, in reference to Illinois Beach State Park, they write that "Warblers, tanagers, grosbeaks and flycatchers occur in fall and spring, ..." This statement could apply to nearly any medium-sized wooded area in Illinois. For the Morton Arboretum, they mention the Townsend's Solitaire, even though in the many decades that birders and ornithologists have been keeping records throughout Illinois, there have been only 19 Townsend's Solitaire sightings documented. It is obvious that the authors wish to recruit more people to birding, but setting up beginners with unrealistic expectations could have the opposite effect.

The Birds of Illinois covers 319 species expected to be seen in Illinois on an annual basis. Each species account, one per page, has an introductory paragraph in which the authors relate unusual or otherwise interesting facts about the species in Illinois. These accounts are creatively written, and will likely be interesting to and enjoyed by beginning birders as well as experienced ornithologists.

Each species account includes an artistically depicted color illustration of the species showing the plumage in which the bird is most likely to be seen in Illinois. This may be a disadvantage of the book, however, for birders seeking to identify species with very different spring and fall plumage (e.g., warblers) or species that have a different plumage for several years before attaining the definitive adult plumage (e.g., gulls). Not finding a bird in the field guide is sure to be a frustration for beginning birders, causing them to search through one of the more comprehensive guides.

Small colored maps of Illinois (about 3 cm high) are included with each species account, showing ranges for breeding, year round, winter, and migration. These maps combined with the section labeled "Status" provide a quick summary of current knowledge for the species in Illinois. DeVore, Bailey, and Kennedy do not cite the Illinois Breeding Bird Atlas Project in the "Select References," even though the raw data for the Atlas publication have been available on the Illinois Natural History Survey's web site since 1998. Each species account also includes a summary of information on identification and biology plus suggestions on the best sites to see the highlighted species.

Because the Atlas and the Birds of Illinois were written with different goals in mind, direct comparisons, for the most part, are not justified. But while the scientific Atlas may satisfy the needs of ornithologists and the Birds of Illinois may be suited more to new birders, experienced birders will likely find both publications useful and interesting.

Areas of overlap between both books occur within the species accounts which is not surprising. In short, both books complement one another. And each book offers certain unique information and insights. Of course, the quantitative nature of the Atlas sets it quite apart from the Birds of Illinois. But together, they represent the best and most comprehensive compilation of information on Illinois' bird populations since Bohlen (1989).

Reviewer: Thomas V. Lerczak, Illinois Nature Preserves Commission, 17500 E. CR 1950N, P.O. Box 590, Havana, Illinois 62644.
E-mail: tlerczak@dnrmail.state.il.us

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2005 Annual Meeting Student Awards

Botany Division – Poster Presentation

1st Place

R.V. MURRAY

Southern Illinois University – Carbondale

Diversity of Strand Cells and the Implications for Phylogeny of Liverworts

2nd Place

JUSTIN CUMMINGS

Eastern Illinois University

Transmission of Fungal Endophytes in Seeds of *Festuca*

Botany Division – Paper Presentation

1st Place

SEAN JONES

Eastern Illinois University

Morphological Variability in Interspecific Hybrids of *Flammulina*

Health Sciences Division – Paper Presentation

1st Place

A.J. KNUTSON

Western Illinois University

Investigation of Magnetotactic Bacteria in Western Illinois

2004/2005 Student Research Grant Awards

CHUCK LESEBERG
Northern Illinois University
The Role of Macrocalyx in Tomato Abscission Zone Development

VERNIE SAGUS
University of Illinois at Urbana-Champaign
Systematic Revision of *Acalypha* in the Malesian Region

SUE GALLO
University of Illinois
Effects of Two Methods of Preservation on Stable Isotope Analysis of Insects

JACE ROBINSON
Northern Illinois University
Phylogeography of the Northern Watersnake, *Nerodia sipedon*,
in the Great Lakes Region

ANNE READEL
University of Illinois at Urbana-Champaign
Effects of Habitat Degredation on the Health and Conservation of Painted Turtles

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6. Both genus and species must be given for all organisms used in the investigation.
7. In the text, references should be quoted by the author's name and date, e.g., (Smith, 1960). Footnotes are to be avoided.
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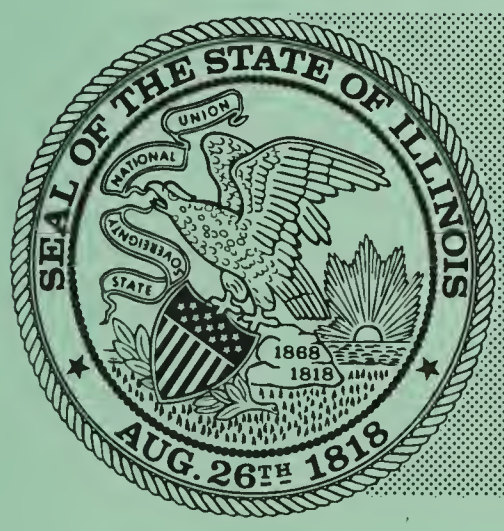
Volume 98, Number 3 & 4 2005



ILLINOIS STATE ACADEMY OF SCIENCE
Founded 1907

Affiliated with the
ILLINOIS STATE MUSEUM, Springfield

ISSN 0019-2252
PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

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Errata

Please note that the cover for Issue #1 & 2 of Transactions volume 98 (2005) presents an incorrect title for the Botany paper authored by McDonnell, Mounteer, Owen, and Todd. The correct listing is shown below:

Botany Papers

McDonnell, A.L., A.M. Mounteer, H.R. Owen, and B.L. Todd
Influence of Stem Cutting and Glyphosate Treatment of *Lonicera maackii*, an Exotic and Invasive Species, on Stem Regrowth and Native Species Richness..... 1

The manuscript appears beginning on page 1 with its appropriate title, however, you may wish to correct this error on the back cover of your personal copy.

Issue 3&4 of 2005 now continues in its entirety, beginning on page 97 with the article by Hyerczyk.

MAR 2 2006

Transactions of the Illinois State Academy of Science
(2005), Volume 98, #3&4, pp. 97-122

received 12/15/04
accepted 12/26/05

The Lichen Flora of Ten Chicago Parks, Chicago Park District, Chicago, Illinois

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ABSTRACT

Forty-five species of lichens are reported from 10 parks owned and managed by the Chicago Park District. Twenty-four species are of the crustose growth form and 21 are foliose. Twenty species are considered to be common, 6 are frequent, 10 are occasional, and 9 are rare. Nine species (*Caloplaca cf. crenulatella, Candelaria concolor*, *Hyperphyscia adglutinata, Lecanora dispersa, Phaeophyscia pusilloides*, *Physcia millegrana*, *Physcia stellaris*, *Physciella chloantha,* and *Xanthomendoza fallax*) were found at all 10 parks and are generally common throughout the Chicago metropolitan area. Norway Maple (*Acer platanoides*) and Red Oak (*Quercus rubra*) are the most common *corticolous* substrates. Weathered concrete is the most common *saxicolous* substrate, and weathered wood is the most common *lignicolous* substrate. A key to the lichen flora, an annotated species list, and checklists by substrates and parks are provided herein.

INTRODUCTION

The Chicago Park District (CPD) is one of the largest park districts in the United States. Since the establishment of the city's first park in 1834, the citizens of Chicago have been provided with many cultural, physical, and recreational opportunities, as well as open space. According to Mary Vanhaaften and Nathan Schroeder (pers. comm.), over 570 parks had been established by 2004, with a coverage of over 2,994 hectares (7,400 acres) of land. The total area for this study was 1,149 hectares (2,839 acres).

Although Calkins (1896) and Wilhelm (1998) have published floras to the lichens of the Chicago region, no lichenological studies have been specifically dedicated to any of the properties owned by the CPD. This project was undertaken to document the lichen flora and collect voucher specimens, and to provide information on the growth forms, substrates, and relative frequency of these organisms in the parks. A key to the lichen flora was also prepared.

MATERIALS AND METHODS

During the summer and fall of 2003, 10 parks owned and managed by the CPD were visited at least twice to document the lichen flora there (Figure 1 and Appendix I). The parks selected for this study were older and historically significant parks. All habitats were

examined as the author walked through the parks in an effort to record as completely as possible the lichen flora growing there.

Collections and notes were made as follows:

Voucher specimens were collected and identified using keys by Brodo et al. (2001), Hale (1979), Thomson (2003), and Wilhelm (1998). Spot tests for lichen chemical substances were made on collected specimens with calcium hypochlorite (abbreviated as "C" in the key to the flora) and potassium hydroxide ("KOH"). All collections were made by the author and are indicated in the annotated species list with a collection number following the substrate upon which the collection was made: *Quercus rubra* (#1834). Nomenclature and authorities follow Esslinger (1997). All collections are deposited in the herbarium at the Field Museum of Natural History (F) in Chicago.

Growth form of each species was noted: foliose (leaf-like) or crustose (crust-like).

Substrate that each species was growing on was noted: saxicolous (concrete, dolomite, or granite), corticolous (bark of trees or shrubs), lignicolous (wood or decorticate logs), or miscellaneous (steel). Nomenclature of vascular plants identified as substrates follow Dirr (1998) or Swink and Wilhelm (1994).

Frequency of each species was noted: rare, occasional, frequent, or common. Values were assigned within the context of the parks in this study and not necessarily with reference to the entire Chicago region. Assignment of categories was based on the following criteria: rare (found at 1 park), occasional (2–3 parks), frequent (4–5 parks), and common (6–10 parks).

DESCRIPTION OF THE STUDY AREA

According to Swink and Wilhelm (1994), the city of Chicago lies mainly in the Chicago Lake Plain Section of the Lake Plain Natural Division, and to a lesser extent, in the Illinois Dunes Section. The Chicago Lake Plain Section is an area once covered by glacial Lake Chicago, where mesic and wet prairie marsh grew up on the nearly level lacustrine, silty clay deposits of the ancient lakebed. The Illinois Dunes Section consists of low beach ridges and swales, as well as an open community of sand prairie, sand savanna, and marsh. Topography is generally level, with elevations ranging from 178 meters (585 feet) to 183 meters (600 feet) above mean sea level.

The climate is predominately temperate; from relatively warm in summer to relatively cold in winter (Wood 2001). The average annual precipitation is 91 centimeters (35.8 inches); the highest rainfall is in August. Mean average temperature for the month of January is ¼5.83°C (21.5°F), with a mean high of ¼1.66°C (29°F) and a mean low of ¼10.6°C (12.9°F). Mean average temperature for the month of July is 22.8°C (73.2°F), with a mean high of 28.7°C (83.7°F) and a mean low of 17.0°C (62.6°F).

RESULTS AND DISCUSSION

The lichen flora of the 10 Chicago parks consisted of 45 species in 26 genera. Twenty-four species (53%) were of the crustose form and 21 (47%) were foliose. Twenty species (45%) were considered to be common, 6 (13%) were frequent, 10 (22%) were occasional, and 9 (20%) were rare. None of the lichens was determined to be threatened or endangered in Illinois. Nine species (*Caloplaca cf. crenulatella*, *Candelaria concolor*, *Hyperphyscia adglutinata, Lecanora dispersa, Phaeophyscia pusilloides*, *Physcia millegrana*, *P. stellaris*, *Physciella chloantha,* and *Xanthomendoza fallax*) were found at all 10 parks and are generally common throughout the Chicago metropolitan area. The floral distribution pattern is pan-temperate, with most species having "broad tolerances with regard to habitat and climate" (Brodo et al. 2001).

Lichens were found on 61 different species of trees or shrubs. The 10 most common corticolous substrates were *Acer platanoides* and *Quercus rubra* (each with 21 lichens); *Gleditsia triacanthos* (20 lichens); *Tilia americana* (18 lichens); *Populus deltoides* (17 lichens); *Acer saccharinum, Crataegus mollis* and *Fraxinus pennsylvanica* var. *subintegerrima* (each with 15 lichens); *Morus alba* (13 lichens); and *Celtis occidentalis* (12 lichens). The remaining trees and shrubs each supported between one and 11 species of lichens.

Lichens were also found on saxicolous materials such as weathered concrete (12 lichens) and dolomite (9 lichens), and on lignicolous materials such as weathered wood (18 lichens) and decorticate logs (7 lichens). Weathered steel was the substrate for 2 lichen species. A complete list of the lichen substrates and the lichens associated with them is presented in Appendix II.

Calkins' 1896 flora of Chicago and vicinity comprised about 440,000 hectares of land (1,700 square miles) that included geologic features such as morainal deposits of clay and gravel and dolomite outcroppings - both habitats that are absent from the Chicago parks. His flora documents an annotated account of 125 lichen taxa "which translate nomenclaturally and taxonomically into 106 taxa recognized today" (Wilhelm 1998). It is not known whether he visited any of the areas which would eventually be developed into the parks of this study, but it was interesting to note that only 17 species encountered here were found by Calkins. Wilhelm (1998) reported 222 species, but only 39 additional species, including the 17 from Calkins, were found here. Six species (*Caloplaca cf. crenulatella, C. subsoluta, Candelariella aurella, Lecanora cf. rugosella, Phaeophyscia orbicularis* and *Psorotichia cf. schaereri*) are reported as not being found in either of the two aforementioned floras.

Although it is known that lichens are very sensitive to low levels of atmospheric pollutants, there was no attempt to determine the effects of polluted air on the lichens in these parks. Wetmore (1988) however, provided a list of pollution (sulfur dioxide) sensitive lichens from the Indiana Dunes National Lakeshore, which is approximately 80 kilometers (50 miles) southeast of the city of Chicago. Fourteen lichens from this study appear on this list (Appendix III).

Larger parks such as Lincoln Park (1,212 acres with 37 lichen species) and Jackson Park (543 acres with 31 lichen species) had higher numbers of lichens than smaller parks such as McKinley Park (69 acres with 12 lichen species). Results such as these were expected and were probably due to the greater variety of trees and other substrates available for lichen colonization in the larger parks. Checklists of individual parks with their associated lichen species are presented in Appendix IV.

Many of the trees planted on the CPD properties are widely spaced and have matured as open-grown specimens. This growth situation seems to be favorable to lichens, as it allows sunlight to filter down through the upper branches and onto the lowermost portions of the trees. Even on the lower branches and trunks, then, lichens in these conditions can receive energy for their photosynthetic component. Moisture and humidity from the waters of Lake Michigan may also contribute to favorable growing conditions in parks located along the lake. The lower trunks of several trees along the lakeshore in Lincoln Park at Montrose Avenue, for example, were covered with as many as 7 different lichen species.

In shaded woodlands, however, such as those found at North Park Village, fewer numbers of lichens were found. Many of our local native woodlands have closed canopies, and the resultant lack of sunlight is possibly one of the reasons for lower numbers of lichens found there. Hyerczyk (1998) found that lichens were more commonly found along sunny paths or in open situations, where light intensities are fairly high.

In general, lichens seem more prevalent on open-grown trees, though many other factors, such as bark texture, bark pH, moisture, humidity, and tree type can play a role in lichen colonization.

ACKOWLEDGMENTS

The Chicago Park District provided funding for this project. I would like to thank Mary Vanhaaften, Nathan Schroeder, and David Wachtel (all of the Chicago Park District), for their help and cooperation in this study. I would also like to thank Barbara A. Johnson (The Botanical Surveyor) and Dr. Robert Lüking (Field Museum of Natural History, Chicago) for their comments to this paper, Dr. Clifford Wetmore (University of Minnesota, St. Paul) for his help with identification of *Caloplaca*, Dr. Mathias Shultz (Biocenter Klein Flottbek of the University of Hamburg) for assistance with *Psorotichia,* Dr. Jim Bennett for *Lecanora*, Dr. Richard "Dick" Harris (New York Botanical Garden) for *Thelidium*, Dr. Thorston Lumbsch (Field Museum of Natural History, Chicago) for *Lecanora*, Dr. Theodore L. Esslinger (North Dakota State University) for *Phaeophyscia,* and Dr. John W. Sheard (University of Saskatchewan) for *Amandinea.*

KEY TO GROUPS & GENERA

References: Thomson (2003) and Wilhelm (1998).

1. Thallus leaf-like, loosely attached to substrate, both an upper and lower cortex present ..... I - FOLIOSE LICHENS
1. Thallus crust-like, tightly attached to substrate, lacking a lower cortex ..... 2.
   2. Fruiting bodies absent ..... II - STERILE CRUSTOSE LICHENS
   2. Fruiting bodies present ..... 3.
      3. Fruiting body flask-like, embedded in thallus with only apex visible, opening by an apical pore (a perithecium) ..... III - CRUSTOSE LICHENS WITH PERITHECIA
      3. Fruiting body elongated, rounded or disk-like, sessile with upper cortex (an apothecium) ..... IV - CRUSTOSE LICHENS WITH APOTHECIA

I - FOLIOSE LICHENS

1. Thallus orange, yellow, or yellowish green ..... 2.
   2. Thallus orange, KOH+ purple ..... XANTHOMENDOZA
   2. Thallus yellow to yellow green, KOH- ..... 3.
      3. Thallus lemon yellow, lobes to 1 mm wide ..... CANDELARIA
      3. Thallus yellow green, lobes 3–8 mm wide ..... 4.
         4. Medulla C-; pseudocyphellae absent ..... FLAVOPARMELIA
         4. Medulla C+ red; pseudocyphellae present ..... FLAVOPUNCTELIA
1. Thallus various shades of gray ..... 5.
   5. Thallus brownish gray, greenish gray, whitish gray, or dark gray, KOH - ..... 6.
      6. Lobes white pruinose ..... PHYSCONIA
      6. Lobes epruinose ..... 7.
         7. Rhizines absent, thallus tightly attached to substrate ..... HYPERPHYSCIA
         7. Rhizines present, thallus loosely attached to substrate ..... PHAEOPHYSCIA
   5. Thallus whitish gray to bluish gray, KOH+ yellow or rarely KOH- ..... 8.
      8. Lower surface brown to black; medulla KOH+ yellow turning red ..... 9.
         9. Upper cortex with white pseudocyphellae; margins of lobes eciliate, lobes 2–5 mm wide, with squared ends, rhizines to margin ..... PARMELIA
         9. Upper cortex without pseudocyphellae; margins of lobes ciliate, lobes 6–20 mm wide, with rounded ends, wide marginal zone without rhizines ..... PARMOTREMA
      8. Lower surface white to pale tan; medulla KOH- or KOH+ yellow ..... 10.
         10. Thallus KOH- ..... PHYSCIELLA
         10. Thallus KOH+ yellow ..... 11.
            11. Upper cortex with white pseudocyphellae; medulla C+ red ..... PUNCTELIA
            11. Upper cortex without pseudocyphellae; medulla C- ..... PHYSCIA

II - STERILE CRUSTOSE LICHENS

1. Thallus orange, KOH+ purple ..... CALOPLACA
1. Thallus not orange, KOH- ..... 2.
   2. Thallus dark green, C+ pink ..... TRAPELIOPSIS
   2. Thallus lemon yellow, C- ..... CANDELARIELLA

III - CRUSTOSE LICHENS WITH PERITHECIA

1. Thallus corticolous; paraphyses present ..... ANISOMERIDIUM
1. Thallus saxicolous; paraphyses absent ..... 2.
   2. Thallus white or cream colored, thick or thin; spores non-septate ..... VERRUCARIA
   2. Thallus not as above; spores muriform or septate ..... 3.
      3. Thallus squamulose-areolate, dark brown, greenish gray or dark gray; perithecia immersed in thallus, spores muriform ..... ENDOCARPON

3. Thallus thin, continuous to disappearing; consisting of light green granules; perithecia imbedded in substrate, spores 3–septate.....THELIDIUM

IV - CRUSTOSE LICHENS WITH APOTHECIA

1. Photobiont a cyanobacterium; thallus dark green to black, gelatinous; apothecial disk brownish red (lichen restricted to limestone revetments along Lake Michigan in semi-aquatic habitats where it is inundated sporadically or periodically)..... PSOROTICHIA
1. Photobiont a green alga; thallus and apothecia not as above..... 2.
   2. Apothecia round to irregular, blue pruinose, margin lacking or poorly developed; thallus leprose..... ARTHONIA
   2. Apothecia round, disk-like or perithecioid, variously colored, margin well developed; thallus not leprose ..... 3.
      3. Exciple thalloid, with algal cells..... 4.
         4. Spores non-septate..... 5.
            5. Apothecia globose, perithecioid..... THELOCARPON
            5. Apothecia disk-like..... LECANORA
         4. Spores polarilocular or 1–3 septate..... 6.
            6. Spores polarilocular; thallus KOH + or – and apothecia KOH+ purple .....CALOPLACA
            6. Spores 1–3 septate; thallus and apothecia not as above ..... 7.
               7. Spores hyaline; apothecia lemon yellow ..... CANDELARIELLA
               7. Spores brown; apothecia black..... AMANDINEA
3. Exciple without algae..... 8.
   8. Spores brown, 1–septate..... AMANDINEA
   8. Spores hyaline, 3–7 septate..... 9.
      9. Epithecium green in KOH; excipulum paraplectenchymatous..... BACIDINA
      9. Epithecium not green in KOH; excipulum prosoplectenchymatous ..... BACIDIA

ANNOTATED SPECIES LIST AND KEY TO SPECIES*

This annotated list is arranged alphabetically by genera and their species. Frequency and a brief description of habitat are also included. *When more than one species occurs under a genus an additional key to the species has been provided.

AMANDINEA M. Choisy *ex* Scheid. & H. Mayrh.

Reference: Sheard & May (1997).

1. Thallus thin, greenish to gray; apothecia with a thalloid margin; spores ovoid, constricted at septum..... *A. dakotensis*
1. Thallus gray; apothecia lacking a thalloid margin; spores elliptical, not constricted at septum ..... *A. punctata*

Amandinea dakotensis (H. Magn.) P. May & Sheard

Occasional. On the lower trunks of *Acer plantanoides*, *Amelanchier* x *grandiflora*, *Prunus* sp., *Quercus rubra* (#1834), and *Tilia americana* (#1842).

= *Buellia schaereri* in Calkins (1896).

Amandinea punctata (Hoffm.) Coppins & Scheid.

Common. On weathered wood (#1814) and wood rail fencing (#1806), and on the lower trunks and branches of *Acer platanoides, A. saccharinum* (#1799), *Gleditsia triacanthos, Quercus rubra, Tilia americana,* and *T. cordata*.

ANISOMERIDIUM (Müll. Arg.) M. Choisy

Anisomeridium polypori (Ellis & Everh.) M. E. Barr

Occasional. On the lower trunks of *Celtis occidentalis* (#1815) and *Crataegus mollis* (#1803, #1836).

= *Anisomeridium nyssigenum* (Ellis & Everh.) R.C. Harris in Wilhelm (1998).

ARTHONIA Ach.

Arthonia caesia (Flotow) Körber

Occasional. On the lower trunks and branches of *Amelanchier* x *grandiflora*, *Carya ovata* (#1811), *Cercis canadensis*, *Crataegus mollis*, *Quercus macrocarpa*, *Q. rubra*, and *Rhamnus cathartica*.

= *Arthonia lecideella* in Calkins (1896).

BACIDIA De Not.

Bacidia granosa (Tuck.) Zahlbr.

Rare. On weathered concrete (#1850).

BACIDINA Vèzda

Bacidina egenula (Nyl.) Vèzda

Frequent. On weathered wood (#1825), gravel (#1816), and concrete.

= *Biatora inundata* in Calkins (1896).

CALOPLACA Th. Fr.

References: Wetmore (1994, 1996, 1998).

1. Thallus consisting of sorediate areoles, KOH+; apothecia rare ..... *C. microphyllina*
1. Thallus esorediate, KOH + or -; apothecia common, KOH+ ..... 2.
   2. Thallus corticolous, KOH-, bluish gray; apothecial disc yellow or orange, margin white or gray ..... *C. cerina*
   2. Thallus saxicolous, KOH+, variously colored or not evident; apothecial disc yellow with a lighter yellow margin ..... 3.
      3. Thallus yellow, lobed; spores 9–13 μm x 5.5–7.0 μm, isthmus 3.5–4.5 μm ..... *C. subsoluta*
      3. Thallus a thin black crust or not evident (growing within substrate); spores 12–14.0 μm x 5.5–7.0 μm, isthmus 1.5–3 μm ..... *C. cf crenulatella*

Caloplaca cerina (Ehrh. *ex* Hedwig) Th. Fr.
Occasional. On the lower trunks of *Populus deltoides* (#1828, #1925, #1927) and *Tilia americana*.

Caloplaca cf. crenulatella H. Olivier
Common. On weathered dolomitic flagstones (#1804, #1831), concrete (#1782, #1797, #1844), and wood.

Caloplaca microphyllina (Tuck.) Hasse
Frequent. On weathered wood rail fencing (#1807) and on the lower trunks of *Gleditsia triacanthos* (#1810) and *Phellodendron amurense*.
= *Placodium microphyllum* in Calkins (1896).

Caloplaca subsoluta (Nyl.) Zahlbr.
Frequent. On weathered dolomite flagstones (#1802) and weathered concrete (#1784).

CANDELARIA A. Massal.

Candelaria concolor (Dickson) Stein
Common. On steel, decorticate logs, weathered wood, park benches, fencing, weathered concrete, and dolomitic flagstones, and on the lower trunks and branches of *Acer ginnala, A. griseum, A. negundo, A. platanoides, A. saccharinum* (#1778), *A. saccharum, Aesculus glabra, A. hippocastanum, Ailanthus altissima, Amelanchier* x *grandiflora, Betula nigra, B. papyrifera, Catalpa speciosa, Celtis occidentalis, Cercis canadensis, Cornus florida, Crataegus crus-galli, C. mollis, Elaeagnus angustifolia, Euonymus alatus, E. hamiltonianus, Fraxinus excelsior, F. pennsylvanica, F. pennsylvanica* var. *subintegerrima* (#1780), *Ginkgo biloba, Gleditsia triacanthos, Gymnocladus dioica, Juglans nigra, Liquidambar styraciflua, Malus* sp., *Morus alba, Phellodendron amurense, Pinus parviflora, Platanus occidentalis* (#1787), *Populus alba, P. deltoides, Prunus serotina, Prunus* sp., *Quercus alba, Q. bicolor, Q. imbricaria, Q. macrocarpa, Q. palustris, Q. rubra, Rhamnus cathartica, Rhus typhina, Robinia pseudoacacia, Salix amygdaloides, S. babylonica, Syringa vulgaris, Thuja occidentalis, Tilia americana, T. cordata, Ulmus americana,* and *U. pumila*.
= *Teloschistes concolar* in Calkins (1896).

CANDELARIELLA Müll. Arg.

References: Harris & Buck (1978), Thomson (2003).

1. Thallus consisting of round, flattened, sorediate areoles; apothecia rare ..... *C. reflexa*
1. Thallus lacking or not evident (growing within substrate); apothecia common ..... *C. aurella*

Candelariella aurella (Hoffm.) Zahlbr.
Occasional. On weathered concrete (#1849, #1926).

Candelariella reflexa (Nyl.) Lettau
Frequent. On weathered wood rail fencing (#1809), and on the lower branches of *Acer platanoides, Crataegus mollis* (#1812), *Morus alba* (#1830), *Quercus rubra,* and *Salix babylonica*.

ENDOCARPON Hedwig

Endocarpon pusillum Hedwig
Common. On weathered dolomitic flagstones (#1801) and concrete (#1781, #1845).

FLAVOPARMELIA Hale

Flavoparmelia caperata (L.) Hale
Common. On weathered wood and decorticate logs (#1848), and on the trunks and lower branches of *Acer platanoides*, *Celtis occidentalis*, *Gleditsia triacanthos*, *Populus deltoides*, *Quercus rubra*, and *Tilia americana*.
= *Parmelia caperata* in Calkins (1896).

FLAVOPUNCTELIA (Krog) Hale

Reference: Brodo, I.M., S. D. Sharnoff, and S. Sharnoff (2001).

1. Pseudocyphellae conspicuous; soralia laminal and marginal, rounded ..... *F. flaventior*
1. Pseudocyphellae sparse and inconspicuous; soralia marginal and crescent shaped ..... *F. soredica*

Flavopunctelia flaventior (Stirton) Hale
Frequent. On the lower trunks of *Gleditsia triacanthos* (#1800), *Quercus rubra*, and *Tilia americana.*

Flavopunctelia soredica (Nyl.) Hale
Common. On the lower trunks of *Acer platanoides*, *Cercis canadensis* (#1835), and *Gleditsia triacanthos* (#1795, #1823).

HYPERPHYSCIA Müll. Arg.

Hyperphyscia adglutinata (Flörke) H. Mayrh. & Poelt
Common. On weathered wood rail fencing, and on the lower trunks and branches of *Acer ginnala*, *A. negundo*, *A. platanoides*, *A. saccharinum*, *A. saccharum*, *Aesculus glabra*, *A. hippocastanum*, *Ailanthus altissima*, *Catalpa speciosa*, *Celtis occidentalis, Cercis canadensis*, *Crataegus crusgalli*, *C. mollis*, *Euonymus alatus*, *E. hamiltonianus*, *Fraxinus excelsior*, *F. pennsylvanica*, *F. pennsylvanica* var. *subintegerrima*, *Ginkgo biloba*, *Gleditsia triacanthos*, *Gymnocladus dioica*, *Juglans nigra*, *Malus* sp., *Morus alba*, *Phellodendron amurense*, *Platanus occidentalis* (#1774), *Populus alba*, *P. deltoides*, *Prunus serotina*, *Prunus* sp., *Pseudotsuga menziesii*, *Quercus alba*, *Q. bicolor*, *Q. macrocarpa*, *Q. rubra*, *Rhamnus cathartica*, *Rhus typhina*, *Salix babylonica*, *Syringa vulgaris*, *Thuja occidentalis*, *Tilia americana*, *Ulmus americana*, and *U. pumila*.
= *Physcia adglutinata* in Calkins (1896).

LECANORA Ach.

References: Brodo, I.M., S. D. Sharnoff, and S. Sharnoff (2001).

1. Thallus saxicolous (rarely lignicolous); apothecial rim gray to white, disc brown ..... *L. dispersa*
1. Thallus corticolous; apothecia not as above ..... 2.
   2. Apothecial disc white pruinose ..... *L. hagenii*
   2. Apothecial disc epruinose ..... 3.
      3. Thallus gray, ashy gray or brownish gray ..... 4.

4. Thallus thick; apothecia to 2mm broad, margins smooth to varicose, thick.. *L. rugosella*
4. Thallus thin; apothecia to 0.5 mm broad, flat, margins thin..... *L. cf. umbrina*
3. Thallus yellowish green ..... 5.
5. Apothecia irregular, rim disappearing with age ..... *L. symmicta*
5. Apothecia round, rim ecorticate, appearing sorediate or granular..... *L. strobilina*

Lecanora dispersa (Pers.) Sommerf.

Common. On weathered wood (#1826), concrete (#1783, #1798), granite, and dolomite flagstones.

Lecanora hagenii (Ach.) Ach.

Occasional. On the lower trunks of *Acer saccharinum*, *Aesculus hippocastanum*, *Crataegus monogyna*, *Fraxinus pennsylvanica* var. *subintegerrima* (#1832), *Gleditsia triacanthos*, *Gymnocladus dioica*, *Populus deltoides*, *Prunus serotina* (#1841), *Pseudolarix amabilis*, *Quercus bicolor*, *Q. rubra* (#1833), *Ulmus americana* (#1827), and *U. pumila*.

Lecanora cf. rugosella Zahlbr.

Rare. On the lower trunks of *Acer platanoides* (#1851) only at Montrose Avenue beach. This lichen was found on several trees that were purchased from a nursery in Wisconsin and may be an introduced species to the Chicago area.

Lecanora strobilina (Sprengel) Kieffer

Occasional. On the lower trunks of *Acer platanoides*, *Prunus* sp., *Quercus alba*, and *Q. macrocarpa* (#1821).

Lecanora symmicta (Ach.) Ach.

Frequent. On weathered wood rail fencing, and on the lower branches of *Acer platanoides*, *A. saccharinum*, *Celtis occidentalis*, *Gleditsia triacanthos*, *Gymnocladus dioica*, *Populus deltoides*, *Prunus* sp., *Quercus macrocarpa* (#1820), and *Tilia americana*.
= *Lecanora varia* var. *symmicta* in Calkins (1896).

Lecanora cf. umbrina (Ach.) A. Massal.

Rare. On weathered wood rail fencing (#1808).

PARMELIA Ach.

Parmelia sulcata Taylor

Common. On weathered wood and decorticate logs, and on the lower trunks and branches of *Acer saccharinum*, *Crataegus mollis*, *Fraxinus pennsylvanica* var. *subintegerrima*, *Ginkgo biloba*, *Gleditsia triacanthos* (#1792), *Juglans nigra*, *Populus deltoides*, *Quercus alba*, *Q. rubra*, and *Tilia americana*.
= *Parmelia saxatilis* var. *sulcata* in Calkins (1896).

PARMOTREMA A. Massal.

Parmotrema hypotropum (Nyl.) Hale

Common. On the lower trunks and branches of *Acer platanoides*, *A. saccharinum* (#1822), *Fraxinus excelsior*, *Gleditsia triacanthos*, *Quercus rubra*, *Tilia americana*, and *Ulmus americana*.

PHAEOPHYSCIA Moberg

Reference: Esslinger (1978).

1. Thallus esorediate..... *P. ciliata*
1. Thallus sorediate ..... 2.
2. Medulla orange-red ..... *P. rubropulchra*

2. Medulla white ..... 3.
   3. Lobe tips of thallus with pale cortical hairs ..... *P. hirsuta*
   3. Lobe tips lacking cortical hairs ..... 4.
      4. Soredia in capitate pustules on raised thallus lobes ..... *P. pusilloides*
      4. Soredia mostly marginal and laminal ..... *P. orbicularis*

Phaeophyscia ciliata (Hoffm.) Moberg

Common. On the lower trunks and branches of *Acer platanoides*, *A. saccharinum*, *Ailanthus altissima*, *Fraxinus pennsylvanica* var. *subintegerrima* (#1790), *Gleditsia triacanthos*, *Gymnocladus dioica*, *Morus alba*, *Platanus occidentalis*, *Populus alba*, *P. deltoides*, *Tilia americana*, *Ulmus americana*, and *U. pumila*.

= *Physcia obscura* in Calkins (1896).

Phaeophyscia hirsuta (Mereschk.) Essl.

Common. On weathered limestone revetments along the lakeshore (#1929), weathered concrete, and wood park benches, and on the lower trunks and branches of *Catalpa speciosa, Fraxinus pennsylvanica, F. pennsylvanica* var. *subintegerrima, Morus alba, Populus alba, P. deltoides* (#1772), *Salix babylonica, Tilia americana,* and *Ulmus pumila.*

= *Phaeophyscia cernohorskyi* (Nàdv.) Essl. in Wilhelm (1998).

Phaeophyscia orbicularis (Necker) Moberg

Rare. On weathered limestone revetments along the lakeshore (#1930).

Phaeophyscia pusilloides (Zahlbr.) Essl.

Common. On weathered concrete and granitic boulders, and on the lower trunks and branches of *Acer ginnala*, *A. platanoides*, *A. saccharinum* (#1775), *Aesculus glabra*, *A. hippocastanum*, *Ailanthus altissima*, *Celtis occidentalis* (#1794), *Crataegus crusgalli*, *Crataegus mollis*, *Euonymus alatus*, *E. hamiltonianus*, *Fraxinus pennsylvanica*, *F. pennsylvanica* var. *subintegerrima*, *Gleditsia triacanthos*, *Gymnocladus dioica*, *Juglans nigra*, *Malus* sp., *Morus alba*, *Phellodendron amurense*, *Platanus occidentalis* (#1786), *Populus alba*, *P. deltoides*, *Quercus bicolor*, *Q. palustris*, *Q. rubra*, *Rhamnus cathartica*, *Salix amygdaloides*, *S. babylonica*, *Syringa vulgaris*, *Taxodium distichum*, *Tilia americana*, and *Ulmus americana*.

Phaeophyscia rubropulchra (Degel.) Essl.

Occasional. On decorticate logs and on the lower trunks and branches of *Acer platanoides*, *A. saccharinum*, *Crataegus mollis*, *Fraxinus pennsylvanica*, *F. pennsylvanica* var. *subintegerrima* (#1813), *Gleditsia triacanthos*, *Morus alba*, *Populus deltoides*, *Prunus serotina,* and *Quercus rubra*.

PHYSCIA (Schreber) Michaux

Reference: Thomson (1963).

1. Thallus esorediate ..... *P. stellaris*
1. Thallus sorediate ..... 2.
   2. Tips of lobes inflated and hood-shaped, ciliate, soredia under the lobes ..... *P. adscendens*
   2. Tips of lobes neither hood-shaped nor ciliate, soredia along margins of lobes ..... *P. millegrana*

Physcia adscendens (Fr.) H. Olivier

Common. On weathered wood, and on the lower trunks and branches of *Acer platanoides*, *A. saccharinum*, *Celtis occidentalis*, *Crataegus mollis*, *Fraxinus pennsylvanica* var. *subintegerrima*, *Ginkgo biloba*, *Gleditsia triacanthos*, *Gymnocladus dioica*, *Juglans nigra*, *Morus alba*, *Phellodendron amurense*, *Platanus occidentalis*, *Populus alba*, *P. deltoides* (#1840), *Prunus* sp., *Quercus bicolor* (#1796), *Q. macrocarpa*, *Q. rubra*, *Salix amygdaloides*, *Tilia americana*, *Ulmus americana,* and *U. pumila*.

Physcia millegrana Degel.

Common. On steel, decorticate logs, and weathered wood rail fencing, and on the lower trunks and branches of *Acer ginnala*, *A. griseum*, *A. negundo*, *A. platanoides*, *A. saccharinum*, *A. saccharum*, *Aesculus hippocastanum*, *Ailanthus altissima*, *Amelanchier* x *grandiflora*, *Betula papyrifera*, *Catalpa speciosa*, *Celtis occidentalis*, *Cercis canadensis*, *Crataegus crusgalli*, *C. mollis*, *Euonymus alatus*, *E. hamiltonianus*, *Fraxinus excelsior*, *F. pennsylvanica*, *F. pennsylvanica* var. *subintegerrima*, *Ginkgo biloba*, *Gleditsia triacanthos* (#1785), *Gymnocladus dioica*, *Juglans nigra*, *Lonicera* sp., *Malus* sp., *Morus alba*, *Phellodendron amurense*, *Pinus parviflora*, *Platanus occidentalis*, *Populus alba*, *P. deltoides*, *Prunus serotina*, *Prunus* sp., *Quercus alba*, *Q. bicolor*, *Q. imbricaria*, *Q. macrocarpa*, *Q. palustris*, *Q. rubra*, *Rhamnus carthartica*, *Robinia pseudoacacia*, *Salix amygdaloides*, *S. babylonica*, *Syringa vulgaris*, *Taxodium distichum*, *Thuja occidentalis*, *Tilia americana*, *Ulmus americana* (#1777), and *U. pumila*.
= *Physcia tribacia* in Calkins (1896).

Physcia stellaris (L.) Nyl.

Common. On weathered wood, park benches, and concrete, and on the lower trunks and branches of *Acer ginnala*, *A. griseum, A. negundo, A. platanoides, A. saccharinum, A. saccharum, Aesculus hippocastanum, Ailanthus altissima*, *Amelanchier* x *grandiflora, Betula nigra, B. papyrifera, Catalpa speciosa, Celtis occidentalis, Cercis canadensis, Crataegus crus-galli, C. mollis, Elaeagus angustifolia, Euonymus hamiltonianus*, *Fraxinus excelsior, F. pennsylvanica, F. pennsylvanica* var. *subintegerrima* (#1791), *Ginkgo biloba, Gleditsia triacanthos* (#1776), *Gymnocladus dioica, Juglans nigra, Liquidambar styraciflua, Malus* sp., *Morus alba, Phellodendron amurense, Pinus parviflora, Platanus occidentalis, Populus alba, P. deltoides* (#1789), *Prunus serotina, Prunus* sp., *Quercus alba, Quercus bicolor, Q. imbricaria, Q. macrocarpa, Q. palustris, Q. rubra, Rhamnus cathartica, Robinia pseudoacacia, Salix amygdaloides, S. babylonica, Syringa vulgaris, Thuja occidentalis, Tilia americana, T. cordata*, *Ulmus americana,* and *U. pumila*.

PHYSCIELLA Essl.

Physciella chloantha (Ach.) Essl.

Common. On weathered wood rail fencing, decorticate logs, weathered concrete (#1843), and dolomite and granite boulders, and on the lower trunks and branches of *Acer ginnala, A. griseum, A. negundo, A. platanoides, A. saccharinum, A. saccharum, Aesculus glabra, A. hippocastanum, Ailanthus altissima, Catalpa speciosa, Celtis occidentalis, Cercis canadensis, Cornus florida, Crataegus crus-galli, C. mollis*, *Elaeagus angustifolia*, *Euonymus alatus, E. hamiltonianus*, *Fraxinus excelsior, F. pennsylvanica* var. *subintegerrima*, *Ginkgo biloba, Gleditsia triacanthos* (#1773), *Gymnocladus dioica, Juglans nigra, Liquidambar styraciflua, Malus* sp., *Morus alba, Phellodendron amurense, Pinus parviflora*, *Platanus occidentalis, Populus alba, P. deltoides, Prunus serotina, Prunus* sp., *Quercus bicolor, Q. macrocarpa, Q. palustris, Q. rubra*, *Rhamnus cathartica, Rhus typhina, Robinia pseudoacacia*, *Salix amygdaloides, S. babylonica, Syringa vulgaris, Taxodium distichum, Tilia americana, Ulmus americana,* and *U. pumila*.

PHYSCONIA Poelt

Physconia leucoleiptes (Tuck.) Essl.

Common. On the lower trunks and branches of *Acer platanoides, Aesculus glabra*, *Celtis occidentalis, Crataegus mollis*, *Fraxinus pennsylvanica* var. *subintegerrima*, *Morus alba* (#1824), and *Quercus rubra*.
= *Physconia detersa* (Nyl.) Poelt in Wilhelm (1998).

PSOROTICHIA (Nyl.) Nyl.

Psorotichia cf. schaereri (Nyl.) Tuck.

Rare. On weathered limestone revetments along the lakeshore (#1854). There is a specimen at the Field Museum of Natural History (F) in Chicago that was collected by Calkins in 1897 from Deer Park (today known as Matthiessen State Park) near Utica, Illinois.

PUNCTELIA Krog

References: Krog (1982), Brodo, I.M., S. D. Sharnoff, and S. Sharnoff (2001).

1. Thallus isidiate; medulla C+ red..... *P. rudecta*
1. Thallus without isidia; medulla C+ pink .....*P. graminicola*

Punctelia graminicola (B. B. de Lesd.) Egan
Rare. On the lower trunk of *Gleditsia triacanthos* (#1805).
= *Punctelia semansiana* (Culb. & C. Culb.) Krog in Wilhelm (1998).

Punctelia rudecta (Ach.) Krog
Occasional. On the lower trunks of *Acer platanoides, Gleditsia triacanthos*, and *Quercus rubra* (#1839).
= *Punctelia borreri* var. *rudecta* in Calkins (1896).

THELIDIUM A. Massal.

Thelidium zwackhii (Hepp) Massal.
Rare. On weathered concrete (#1818) and gravel (#1817, #1819). According to Theodore Esslinger and Dick Harris (pers. comm.), this is a European species synonymous with *Thelidium microcarpum* (Leight.) A. L. Sm.
= *Thelidium microcarpum* (Leight.) A.L. Sm. in Wilhelm (1998).

THELOCARPON Nyl. *ex* Hue

Thelocarpon laureri (Flotow) Nyl.
Rare. On weathered wood rail fencing (#1829).

TRAPELIOPSIS Hertel & Gotth. Schneider

Trapeliopsis flexuosa (Fr.) Coppins & P. James
Rare. On weathered wood (#1847).

VERRUCARIA Schrader

Verrucaria calkinsiana Servít
Occasional. On weathered concrete, limestone (#1846), and sandstone (#1853).
= *Verrucaria muralis* in Calkins (1896).

XANTHOMENDOZA S. Kondr. & Kärnefelt

Reference: Lindblom (1997).

1. Lobes narrow, less than 0.5 mm wide; soredia at margins and on lower surface of lobes...*X. fulva*
1. Lobes 0.8-1.4 mm wide; soralia labriform and marginal, soredia produced in marginal slits between the upper and lower cortex ..... *X. fallax*

Xanthomendoza fallax (Hepp) Søchting, Kärnefelt & S. Kondr.
Common. On decorticate logs and weathered wood rail fencing, and on the lower trunks and branches of *Acer ginnala, A. negundo, A. platanoides, A. saccharinum, Ailanthus altissima, Catalpa speciosa, Celtis occidentalis, Cercis canadensis, Crataegus mollis, Fraxinus excelsior, F. pennsylvanica* var. *subintegerrima* (#1779), *Ginkgo biloba, Gleditsia triacanthos* (#1771), *Gymnocladus dioica, Juglans nigra, Malus* sp., *Morus alba, Platanus occidentalis, Populus alba, P. deltoides, Prunus serotina, Quercus bicolor, Q. macrocarpa, Q. rubra, Salix*

amygdaloides, S. babylonica, Tilia americana, Ulmus americana (#1793, #1838), and *U. pumila.*

Xanthomendoza fulva (Hoffm.) Søchting, Kärnefelt & S. Kondr.

Common. On the lower trunks and branches of *Crataegus mollis, Fraxinus pennsylvanica* var. *subintegrimma, Juglans nigra* (#1788), *Phellodendron amurense, Platanus occidentalis, Populus deltoides, Quercus macrocarpa,* and *Q. rubra.*

= *Theloschistes lychneus* in Calkins (1896).

= *Xanthoria* sp. #1 in Wilhelm (1998).

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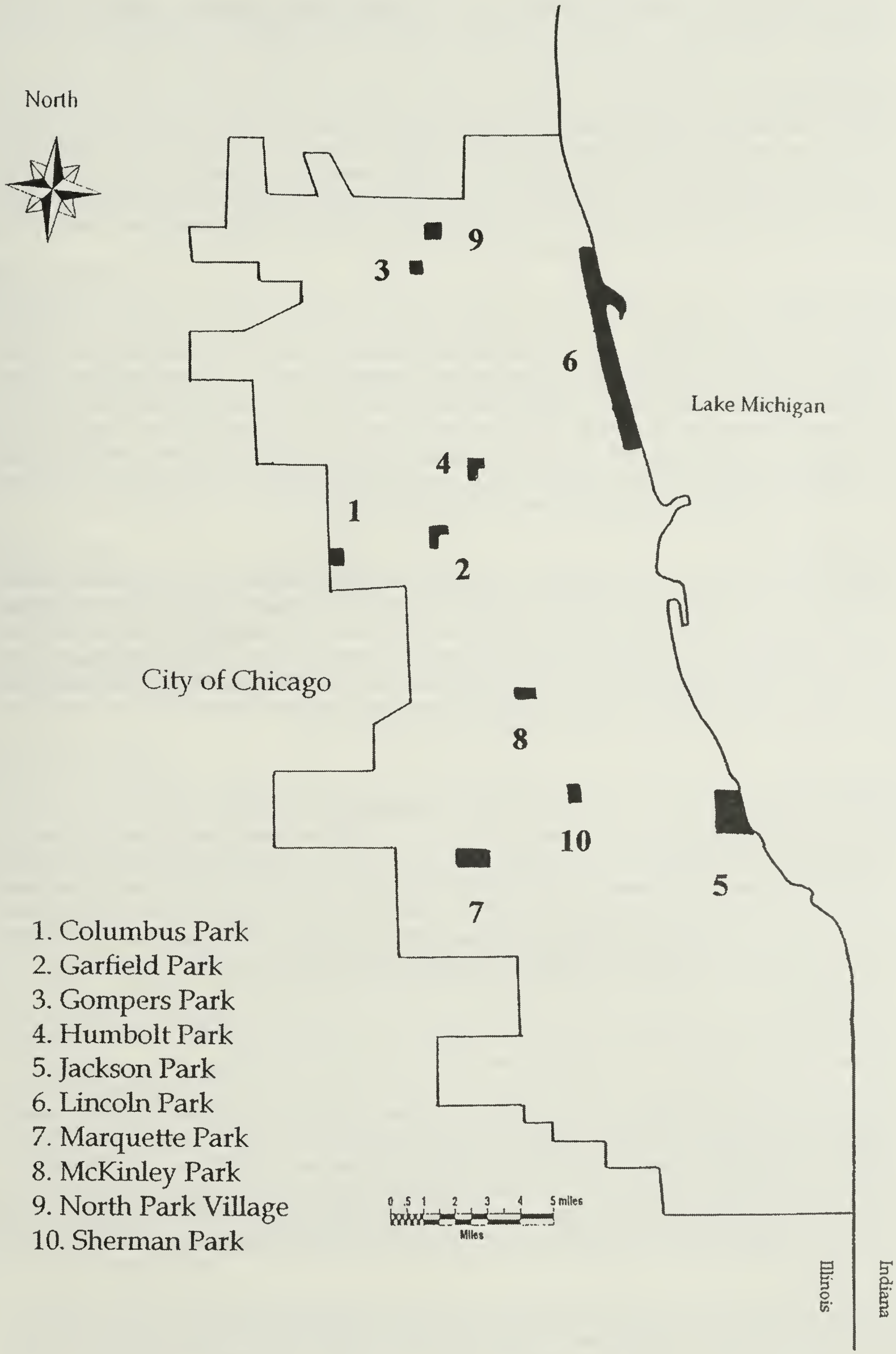
Figure 1. Map of study area.



Appendix 1.

A brief description of each park follows and includes lichen substrates, park size, and location.

Columbus Park
Amenities include picnic areas, a golf course, and a lagoon. Several substrates were available here, including weathered concrete, dolomite flagstones, and wood rail fencing, as well as a variety of trees. Those recorded were *Acer platanoides, A. saccharinum, Celtis occidentalis, Crataegus mollis, Fraxinus pennsylvanica* var. *subintegerrima, Gleditsia triacanthos, Juglans nigra, Morus alba, Quercus bicolor, Q. macrocarpa, Q. rubra, Rhus typhina, Tilia americana,* and *Ulmus americana.* Park size is 55 hectares (135 acres) and location is NE & SE ¼ Sec 17, T39N, R13E.

Garfield Park
Amenities include the Garfield Park Conservatory, picnic areas, ball fields, and a lagoon. Several substrates were available here, including weathered concrete, as well as a variety of trees. Those recorded were *Acer saccharinum, Aesculus glabra, A. hippocastanum, Catalpa speciosa, Celtis occidentalis, Cercis canadensis, Crataegus crus-galli, C. mollis, Fraxinus pennsylvanica* var. *subintegerrima, Ginkgo biloba, Gleditsia triacanthos, Gymnocladus dioica, Juglans nigra, Morus alba, Platanus occidentalis, Populus alba, P. deltoides, Prunus serotina, Quercus bicolor, Q. rubra, Tilia americana, Ulmus americana,* and *U. pumila.* Park size is 75 hectares (185 acres) and location is SW ¼ Sec 11, T39N, R13E and NW ¼ Sec 14, T39N, R13E.

Gompers Park
Amenities include picnic areas, ball fields, a wetland restoration, and a lagoon. Several substrates were available here, including weathered concrete, as well as a variety of trees. Those recorded were *Acer negundo, A. platanoides, A. saccharinum, Ailanthus altissima, Betula nigra, Celtis occidentalis, Crataegus crus-galli, C. mollis, Fraxinus pennsylvanica* var. *subintegerrima, Juglans nigra, Morus alba, Platanus occidentalis, Populus deltoides, Prunus serotina, Quercus macrocarpa, Q. palustris, Q. rubra, Tilia americana, Ulmus americana,* and *U. pumila.* Park size is 16 hectares (39 acres) and location is NE & SE ¼ Sec 10, T40N, R13E.

Humboldt Park
Amenities include picnic areas, ball fields, and a lagoon. Several substrates were available here, including weathered concrete, as well as a variety of trees. Those recorded were *Acer platanoides, A. saccharinum, A. saccharum, Aesculus hippocastanum, Celtis occidentalis, Crataegus crus-galli, C. mollis, Fraxinus pennsylvanica* var. *subintegerrima., Ginkgo biloba, Gleditsia triacanthos, Gymnocladus dioica, Juglans nigra, Morus alba, Platanus occidentalis, Populus alba, Quercus alba, Q. bicolor, Q. rubra, Rhamnus cathartica, Syringa vulgaris, Tilia americana,* and *Ulmus americana.* Park size is 84 hectares (207 acres) and location is NW ¼ Sec 1, T39N, R13E.

Jackson Park
Amenities include the Museum of Science and Industry, picnic areas, ball fields, a golf course, and a lagoon. Several substrates were available here, including weathered wood, concrete, and dolomite flagstones, as well as a variety of trees. Those recorded were *Acer ginnala, A. platanoides, A. saccharinum, Ailanthus altissima, Catalpa speciosa, Celtis occidentalis, Crataegus mollis, Euonymous alatus, Fraxinus pennsylvanica* var. *subintegerrima, Ginkgo biloba, Gleditsia triacanthos, Gymnocladus dioica, Juglans nigra, Morus alba, Phellodendron amurense, Platanus occidentalis, Populus alba, P. deltoides, Quercus alba, Q. imbricaria, Q. macrocarpa, Q. rubra, Salix babylonica, Syringa vulgaris, Tilia americana, Ulmus americana,* and *U. pumila.* Park size is 220 hectares (543 acres) and location is NW & SW ¼ Sec 13, T38N, R14E and NW & NE ¼ Sec 24, T38N, R14E.

Lincoln Park
Amenities include the Lincoln Park Zoo and Conservatory, the Peggy Notebaert Nature Museum, picnic areas, ball fields, and lagoons, as well as several beaches and harbors along the shore of Lake Michigan. Several substrates were available here, including weathered steel, concrete, dolo-

mite, decorticate logs, and wood, as well as a variety of trees. Those recorded were *Acer griseum, A. negundo, A. platanoides, A. saccharinum, Aesculus hippocastanum, Ailanthus altissima, Betula papyrifera, Catalpa speciosa, Celtis occidentalis, Cornus florida, Crataegus crus-galli, C. mollis, Elaeagnus angustifolia, Euonymus hamiltonianus, Fraxinus excelsior, F. pennsylvanica* var. *subintegerrima, Ginkgo biloba, Gleditsia triacanthos, Gymnocladus dioica, Juglans nigra, Malus* sp., *Morus alba, Pinus parviflora, Platanus occidentalis, Populus deltoides, Prunus serotina, Prunus* sp., *Quercus alba, Q. bicolor, Q. macrocarpa, Q. rubra, Rhamnus cathartica, Robinia pseudoacacia, Salix amygdaloides, S. babylonica, Tilia americana, T. cordata, Ulmus americana,* and *U. pumila*. Park size is 490 hectares (1,212 acres) and locations are as follows: North Avenue Beach (NE & SE ¼ Sec 33, T40N, R14E), Diversey Harbor (NE & SE ¼ Sec 28 T40N, R14E), Belmont Harbor (NE & SE ¼ Sec 21, T40N, R14E), Montrose Harbor (NE & SE ¼ Sec 16, T40N, R14E), and Foster Avenue Beach (NE & SE ¼ Sec 8, T40N, R14E).

Marquette Park
Amenities include picnic areas, ball fields, a golf course, and a lagoon. Several substrates were available here, including weathered concrete and weathered wood rail fencing, as well as a variety of trees. Those recorded were *Acer platanoides, A. saccharinum, A. saccharum, Aesculus hippocastanum, Catalpa speciosa, Celtis occidentalis, Cercis canadensis, Crataegus mollis, Fraxinus pennsylvanica, F. pennsylvanica* var. *subintegerrima, Gleditsia triacanthos, Gymnocladus dioica, Juglans nigra, Liquidambar styraciflua, Malus* sp., *Morus alba, Platanus occidentalis, Populus alba, P. deltoides, Prunus* sp., *Quercus alba, Q. macrocarpa, Q. palustris, Q. rubra, Salix babylonica, Syringa vulgaris, Tilia americana, Ulmus americana,* and *U. pumila*. Park size is 131 hectares (323 acres) and location is SE ¼ Sec 23, T38N, R13E and SW ¼ Sec 24, T38N, R13E.

McKinley Park
Amenities include picnic areas, ball fields, and a lagoon. Several substrates were available here, including weathered concrete and wooden park benches, as well as a variety of trees. Those recorded were *Acer saccharinum, Aesculus hippocastanum, Catalpa speciosa, Celtis occidentalis, Fraxinus pennsylvanica* var. *subintegerrima, Ginkgo biloba, Gleditsia triacanthos, Gymnocladus dioica, Platanus occidentalis, Populus deltoides, Quercus bicolor, Ulmus americana,* and *U. pumila*. Park size is 28 hectares (69 acres) and location is SW ¼ Sec 31, T39N, R14E.

North Park Village
Amenities include hiking trails, picnic areas, and natural areas. North Park Village is unique in that it includes a 19 hectare (46-acre) nature preserve, an educational facility (Nature Center), and 8 hectares (19 acres) of additional land. These are situated within a larger complex of buildings on approximately 63 hectares (155 acres) of land formerly housing the City of Chicago's Tuberculosis Sanitarium. Several substrates were available here, including weathered wood, decorticate logs, weathered concrete, and granite and sandstone boulders, as well as a variety of trees. Those recorded were *Acer negundo, A. platanoides, Aesculus glabra, Celtis occidentalis, Crataegus mollis, Fraxinus pennsylvanica, F. pennsylvanica* var. *subintegerrima, Gleditsia triacanthos, Morus alba, Populus deltoides, Quercus bicolor, Q. macrocarpa, Q. rubra, Rhamnus cathartica, Salix babylonica, Tilia americana,* and *Ulmus americana*. Park size is 26 hectares (65 acres) and location is SW ¼ Sec 2, T40N, R13E.

Sherman Park
Amenities include picnic areas, ball fields, and a lagoon. Several substrates were available here, including weathered concrete, as well as a variety of trees. Those recorded were *Acer platanoides, A. saccharinum, Aesculus hippocastanum, Ailanthus altissima, Betula nigra, Celtis occidentalis, Crataegus mollis, Fraxinus pennsylvanica* var. *subintegerrima, Ginkgo biloba, Gleditsia triacanthos, Gymnocladus dioica, Juglans nigra, Morus alba, Platanus occidentalis, Populus alba, P. deltoides, Tilia americana,* and *Ulmus americana*. Park size is 25 hectares (61 acres) and location is SW ¼ Sec 8, T38N, R14E.

Appendix II.

Lichen substrates and their associated lichen species.

Acer ginnala **Maxim. (AMUR MAPLE) 7 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia pusilloides, Physcia millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

Acer griseum **(Franch.) Pax (PAPERBARK MAPLE) 4 species**
Candelaria concolor, Physcia millegrana, P. stellaris, Physciella chloantha

Acer negundo **L. (BOX ELDER) 6 species**
Candelaria concolor, Hyperphyscia adglutinata, Physcia millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

Acer platanoides **L. (NORWAY MAPLE) 21 species**
Amandinea dakotensis, A. punctata, Candelaria concolor, Candelariella reflexa, Flavoparmelia caperata, Flavopunctelia soredica, Hyperphyscia adglutinata, Lecanora cf. rugosella, L. strobilina, L. symmicta, Parmotrema hypotropum, Phaeophyscia ciliata, P. pusilloides, P. rubropulchra, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Physconia leucoleiptes, Punctelia rudecta, Xanthomendoza fallax

Acer saccharinum **L. (SILVER MAPLE) 15 species**
Amandinea punctata, Candelaria concolor, Hyperphyscia adglutinata, Lecanora hagenii, L. symmicta, Parmelia sulcata, Parmotrema hypotropum, Phaeophyscia ciliata, P. pusilloides, P. rubropulchra, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

Acer saccharum **Marshall (SUGAR MAPLE) 5 species**
Candelaria concolor, Hyperphyscia adglutinata, Physcia millegrana, P. stellaris, Physciella chloantha

Aesculus glabra **Willd. (OHIO BUCK-EYE) 5 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia pusilloides, Physciella chloantha, Physconia leucoleiptes

Aesculus hippocastanum **L. (HORSE CHESTNUT) 7 species**
Candelaria concolor, Hyperphyscia adglutinata, Lecanora hagenii, Phaeophyscia pusilloides, Physcia millegrana, P. stellaris, Physciella chloantha

Ailanthus altissima **(Mill.) Swingle (TREE OF HEAVEN) 8 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia ciliata, P. pusilloides, Physcia millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

Amelanchier **x** ***grandiflora*** **Rehd. 'Apple Serviceberry' (SERVICEBERRY) 5 species**
Amandinea dakotensis, Arthonia caesia, Candelaria concolor, Physcia millegrana, P. stellaris

Betula nigra **L. (RIVER BIRCH) 2 species**
Candelaria concolor, Physcia stellaris

Betula papyrifera **Marshall (PAPER BIRCH) 3 species**
Candelaria concolor, Physcia millegrana, P. stellaris

Carya ovata **(Mill.) K. Koch (SHAGBARK HICKORY) 1 species**
Arthonia caesia

***Catalpa speciosa* Warder (HARDY CATALPA) 7 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia hirsuta, Physcia millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Celtis occidentalis* L. (HACKBERRY) 12 species**
Anisomeridium polypori, Candelaria concolor, Flavoparmelia caperata, Hyperphyscia adglutinata, Lecanora symmicta, Phaeophyscia pusilloides, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Physconia leucoleiptes, Xanthomendoza fallax

***Cercis canadensis* L. (REDBUD) 8 species**
Arthonia caesia, Candelaria concolor, Flavopunctelia soredica, Hyperphyscia adglutinata, Physcia millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Cornus florida* L. (FLOWERING DOGWOOD) 2 species**
Candelaria concolor, Physciella chloantha

***Crataegus crusgalli* L. (COCKSPUR HAWTHORN) 6 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia pusilloides, Physcia millegrana, P. stellaris, Physciella chloantha

***Crataegus mollis* (T. & G.) Scheele (DOWNY HAWTHORN) 15 species**
Anisomeridium polypori, Arthonia caesia, Candelaria concolor, Candelariella reflexa, Hyperphyscia adglutinana, Parmelia sulcata, Phaeophyscia pusilloides, P. rubropulchra, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Physconia leucoleiptes, Xanthomendoza fallax, X. fulva

***Crataegus monogyna* Jacq. 'Inermis Compacta' (HAWTHORN) 1 species**
Lecanora hagenii

***Elaeagus angustifolia* L. (RUSSIAN OLIVE) 3 SPECIES**
Candelaria concolor, Physcia stellaris, Physciella chloantha

***Euonymus alatus* (Thunb.) Siebold (WINGED EUONYMUS) 5 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia pusilloides, Physcia millegrana, Physciella chloantha

***Euonymus hamiltonianus* Wallich. (JAPANESE SPINDLE TREE) 6 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia pusilloides, Physcia millegrana, P. stellaris, Physciella chloantha

***Fraxinus excelsior* L. 'Hessei' (EUROPEAN ASH) 7 species**
Candelaria concolor, Hyperphyscia adglutinata, Parmotrema hypotropum, Physcia millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Fraxinus pennsylvanica* Marshall (RED ASH) 7 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia hirsuta, P. pusilloides, P. rubropulchra, Physcia millegrana, P. stellaris

***Fraxinus pennsylvanica* Marshall var. *subintegerrima* (Vahl) Fern. (GREEN ASH) 15 species**
Candelaria concolor, Hyperphyscia adglutinata, Lecanora hagenii, Parmelia sulcata, Phaeophyscia ciliata, P. hirsuta, P. pusilloides, P. rubropulchra, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Physconia leucoleiptes, Xanthomendoza fallax, X. fulva

***Gingko biloba* L. (GINGKO) 8 species**
Candelaria concolor, Hyperphyscia adglutinata, Parmelia sulcata, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Gleditsia triacanthos* L. (HONEY LOCUST) 20 species**
Amandinea punctata, Caloplaca microphyllina, Candelaria concolor, Flavoparmelia caperata, Flavopunctelia flaventior, F. soredica, Hyperphyscia adglutinata, Lecanora hagenii, L. symmicta, Parmelia sulcata, Parmotrema hypotropum, Phaeophyscia ciliata, P. pusilloides, P. rubropulchra, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Punctelia graminicola, Xanthomendoza fallax

***Gymnocladus dioica* (L.) Koch (KENTUCKY COFFEE TREE) 11 species**
Candelaria concolor, Hyperphyscia adglutinata, Lecanora hagenii, L. symmicta, Phaeophyscia ciliata, P. pusilloides, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Juglans nigra* L. (BLACK WALNUT) 10 species**
Candelaria concolor, Hyperphyscia adglutinata, Parmelia sulcata, Phaeophyscia pusilloides, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax, X. fulva

***Liquidambar styraciflua* L. (SWEET GUM) 3 species**
Candelaria concolor, Physcia stellaris, Physciella chloantha

***Lonicera* sp (HONEYSUCKLE) 1 species**
Physcia millegrana

***Malus* sp. (CRAB-APPLE) 7 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia pusilloides, Physcia millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Morus alba* L. (WHITE MULBERRY) 13 species**
Candelaria concolor, Candelariella reflexa, Hyperphyscia adglutinata, Phaeophyscia, ciliata, P. hirsuta, P. pusilloides, P. rubropulchra, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Physconia leucoleiptes, Xanthomendoza fallax

***Phellodendron amurense* Rupr. (AMUR CORK TREE) 9 species**
Caloplaca microphyllina, Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia pusilloides, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fulva

***Pinus parviflora* Siebold and Zucc. (JAPANESE WHITE PINE) 4 species**
Candelaria concolor, Physcia millegrana, P. stellaris, Physciella chloantha

***Platanus occidentalis* L. (SYCAMORE) 10 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia ciliata, P. pusilloides, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax, X. fulva

***Populus alba* L. (WHITE POPLAR) 10 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia ciliata, P. hirsuta, P. pusilloides, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Populus deltoides* Marshall (EASTERN COTTONWOOD) 17 species**
Caloplaca cerina, Candelaria concolor, Flavoparmelia caperata, Hyperphyscia adglutinata, Lecanora hagenii, L. symmicta, Parmelia sulcata, Phaeophyscia ciliata, P. hirsuta, P. pusilloides, P. rubropulchra, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax, X. fulva

***Prunus serotina* Ehrh. (WILD BLACK CHERRY) 8 species**
Candelaria concolor, Hyperphyscia adglutinata, Lecanora hagenii, Phaeophyscia rubropulchra, Physcia millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Prunus* sp. (PLUM/CRABAPPLE) 9 species**
Amandinea dakotensis, Candelaria concolor, Hyperphyscia adglutinata, Lecanora strobilina, L. symmicta, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha

***Pseudolarix amabilis* (J. Nels.) Rehd. (GOLDEN LARCH) 1 species**
Lecanora hagenii

***Pseudotsuga menziesii* (Mirb.) Franco (DOUGLAS FIR) 1 species**
Hyperphyscia adglutinata

***Quercus alba* L. (WHITE OAK) 6 species**
Candelaria concolor, Hyperphyscia adglutinata, Lecanora strobilina, Parmelia sulcata, Physcia millegrana, P. stellaris

***Quercus bicolor* Willd. (SWAMP WHITE OAK) 9 species**
Candelaria concolor, Hyperphyscia adglutinata, Lecanora hagenii, Phaeophyscia pusilloides, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Quercus imbricaria* Michx. (SHINGLE OAK) 3 species**
Candelaria concolor, Physcia millegrana, P. stellaris

***Quercus macrocarpa* Michx. (BUR OAK) 11 species**
Arthonia caesia, Candelaria concolor, Hyperphyscia adglutinata, Lecanora strobilina, L. symmicta, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax, X. fulva

***Quercus palustris* Münchh. (PIN OAK) 5 species**
Candelaria concolor, Phaeophyscia pusilloides, Physcia millegrana, P. stellaris, Physciella chloantha

***Quercus rubra* L. (RED OAK) 21 species**
Amandinea dakotensis, A. punctata, Arthonia caesia, Candelaria concolor, Candelariella reflexa, Flavoparmelia caperata, Flavopunctelia flaventior, Hyperphyscia adglutinata, Lecanora hagenii, Parmelia sulcata, Parmotrema hypotropum, Phaeophyscia pusilloides, P. rubropulchra, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Physconia leucoleiptes, Punctelia rudecta, Xanthomendoza fallax, X. fulva

***Rhamnus cathartica* L. (COMMON BUCKTHORN) 7 species**
Arthonia caesia, Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia pusilloides, Physcia millegrana, P. stellaris, Physciella chloantha

***Rhus typhina* L. (STAGHORN SUMAC) 3 species**
Candelaria concolor, Hyperphyscia adglutinata, Physciella chloantha

***Robinia pseudoacacia* L. (BLACK LOCUST) 4 species**
Candelaria concolor, Physcia millegrana, P. stellaris, Physciella chloantha

***Salix amygdaloides* Andersson (PEACH-LEAVED WILLOW) 7 species**
Candelaria concolor, Phaeophyscia pusilloides, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Salix babylonica* L. (WEEPING WILLOW) 9 species**
Candelaria concolor, Candelariella reflexa, Hyperphyscia adglutinata, Phaeophyscia hirsuta, P. pusilloides, Physcia millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Syringa vulgaris* L. (LILAC) 6 species**
Candelaria concolor, Hyperphyscia adglutinata, Phaeophyscia pusilloides, Physcia millegrana, P. stellaris, Physciella chloantha

***Taxodium distichum* (L.) Richard (BALD CYPRRESS) 3 species**
Phaeophyscia pusilloides, Physcia millegrana, Physciella chloantha

***Thuja occidentalis* L. (EASTERN WHITE CEDAR) 4 species**
Candelaria concolor, Hyperphyscia adglutinata, Physcia millegrana, P. stellaris

***Tilia americana* L. (BASSWOOD) 18 species**
Amandinea dakotensis, A. punctata, Caloplaca cerina, Candelaria concolor, Flavoparmelia caperata, Flavopunctelia flaventior, Hyperphyscia adglutinata, Lecanora symmicta, Parmelia sulcata, Parmotrema hypotropum, Phaeophyscia ciliata, P. hirsuta, P. pusilloides, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Tilia cordata* Mill. (SMALL-LEAVED LINDEN) 3 species**
Amandinea punctata, Candelaria concolor, Physcia stellaris

***Ulmus americana* L. (AMERICAN ELM) 11 species**
Candelaria concolor, Hyperphyscia adglutinata, Lecanora hagenii, Parmotrema hypotropum, Phaeophyscia ciliata, P. pusilloides, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

***Ulmus pumila* L. (SIBERIAN ELM) 10 species**
Candelaria concolor, Hyperphyscia adglutinata, Lecanora hagenii, Phaeophyscia ciliata, P. hirsuta, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Xanthomendoza fallax

(Weathered wood, wood fencing, wood shingles, decorticate logs, etc.) 21 species
Amandinea punctata, Bacidina egenula, Caloplaca cf. crenulatella, C. microphyllina, Candelaria concolor, Candelariella reflexa, Flavoparmelia caperata, Hyperphyscia adglutinata, Lecanora dispersa, L. symmicta, L. cf. umbrina, Parmelia sulcata, Phaeophyscia hirsuta, P. rubropulchra, Physcia adscendens, P. millegrana, P. stellaris, Physciella chloantha, Thelocarpon laureri, Trapeliopsis flexuosa, Xanthomendoza fallax

(Weathered concrete, dolomite, granite, sandstone, limestone, etc.) 16 species
Bacidia granosa, Bacidina egenula, Caloplaca cf. crenulatella, C. subsoluta, Candelaria concolor, Candelariella aurella, Endocarpon pusillum, Lecanora dispersa, Phaeophyscia hirsuta, P. orbicularis, P. pusilloides, Physcia stellaris, Physciella chloantha, Psorotichia cf. schaereri, Thelidium zwackhii, Verrucaria calkinsiana

(Steel) 2 species
Candelaria concolor, Physcia millegrana

Appendix III.

This is a list of a list of pollution (sulfur dioxide) sensitive lichens as proposed by Wetmore (1983).

S (Sensitive) These species are absent when the annual average levels of sulfur dioxide are above 50 μg per cubic meter:

none found here.

SI (Intermediate between Sensitive and Intermediate)

Caloplaca cerina
Candelaria concolor

I (Intermediate): These species are present when the annual average levels of sulfur dioxide are between 50 and 100 μg per cubic meter:

Flavoparmelia caperata
Hyperphyscia adglutinata
Lecanora symmicta
Physcia adscendens
Physcia millegrana
Physcia stellaris
Physconia leucoleiptes
Punctelia rudecta
Xanthomendoza fallax

IT (Intermediate between Intermediate and Tolerant):

Parmelia sulcata

T (Tolerant): These species are present when the annual average levels of sulfur dioxide are over 100 μg per cubic meter:

Amandinea punctata
Lecanora hagenii

Appendix IV.

Checklist of parks and lichen species.

COLUMBUS PARK 24 species
Amandinea punctata
Anisomeridium polypori
Bacidina egenula
Caloplaca cf. crenulatella
C. microphyllina
C. subsoluta
Candelaria concolor
Endocarpon pusillum
Flavoparmelia caperata
Flavopunctelia flaventior
F. soredica
Hyperphyscia adglutinata
Lecanora dispersa
Parmelia sulcata
Parmotrema hypotropum
Phaeophyscia ciliata
P. pusilloides
Physcia adscendens
P. millegrana
P. stellaris
Physciella chloantha
Physconia leucoleiptes
Punctelia rudecta
Xanthomendoza fallax

GARFIELD PARK 19 species
Amandinea punctata
Caloplaca cf. crenulatella
Candelaria concolor
Endocarpon pusillum
Flavopunctelia flaventior
F. soredica
Hyperphyscia adglutinata
Lecanora dispersa
Parmelia sulcata
Parmotrema hypotropum
Phaeophyscia ciliata
P. hirsuta
P. pusilloides
Physcia adscendens
P. millegrana
P. stellaris
Physciella chloantha
Xanthomendoza fallax
X. fulva

GOMPERS PARK 21 species
Amandinea punctata
Bacidina egenula
Caloplaca cf. crenulatella
Candelaria concolor
Candelariella aurella
C. reflexa
Endocarpon pusillum
Flavoparmelia caperata
Hyperphyscia adglutinata
Lecanora dispersa
L. strobilina
L. symmicta
Parmelia sulcata
Phaeophyscia ciliata
P. pusilloides
Physcia millegrana
P. stellaris
Physciella chloantha
Physconia leucoleiptes
Xanthomendoza fallax
X. fulva

HUMBOLT PARK 18 species
Caloplaca cf. crenulatella
Candelaria concolor
Endocarpon pusillum
Flavoparmelia caperata
Flavopunctelia soredica
Hyperphyscia adglutinata
Lecanora dispersa
L. symmicta
Parmelia sulcata
Phaeophyscia hirsuta
P. pusilloides
Physcia adscendens
P. millegrana
P. stellaris
Physciella chloantha

Physconia leucoleiptes
Xanthomendoza fallax
X. fulva

JACKSON PARK 31 species
Amandinea punctata
Bacidina egenula
Caloplaca cerina
C. cf. crenulatella
C. microphyllina
C. subsoluta
Candelaria concolor
Candelariella aurella
C. reflexa
Endocarpon pusillum
Flavoparmelia caperata
Flavopunctelia flaventior
F. soredica
Hyperphyscia adglutinata
Lecanora dispersa
L. symmicta
Parmelia sulcata
Parmotrema hypotropum
Phaeophyscia ciliata
P. hirsuta
P. pusilloides
P. rubropulchra
Physcia adscendens
P. millegrana
P. stellaris
Physciella chloantha
Physconia leucoleiptes
Punctelia rudecta
Thelocarpon laureri
Xanthomendoza fallax
X. fulva

LINCOLN PARK 37 species
Amandinea dakotensis
A. punctata
Arthonia caesia
Bacidia granosa
Caloplaca cerina
C. cf. crenulatella
C. microphyllina
C. subsoluta
Candelaria concolor
Candelariella aurella
C. reflexa
Endocarpon pusillum
Flavoparmelia caperata
Flavopunctelia flaventior
F. soredica
Hyperphyscia adglutinata
Lecanora dispersa
L. hagenii
L. rugosella
L. strobilina
L. symmicta
Parmelia sulcata
Parmotrema hypotropum
Phaeophyscia ciliata
P. hirsuta
P. orbicularis
P. pusilloides
Physcia adscendens
P. millegrana
P. stellaris
Physciella chloantha
Physconia leucoleiptes
Psorotichia cf. schaereri
Punctelia rudecta
Verrucaria calkinsiana
Xanthomendoza fallax
X. fulva

MARQUETTE PARK 28 species
Amandinea dakotensis
A punctata
Arthonia caesia
Bacidina egenula
Caloplaca cf. crenulatella
C. microphyllina
Candelaria concolor
Candelariella reflexa
Endocarpon pusillum
Flavoparmelia caperata
Flavopunctelia soredica
Hyperphyscia adglutinata
Lecanora dispersa
L. hagenii
L. strobilina
L. symmicta
L. cf. umbrina
Parmelia sulcata
Parmotrema hypotropum

Phaeophyscia pusilloides
Physcia adscendens
P. millegrana
P. stellaris
Physciella chloantha
Physconia leucoleiptes
Punctelia graminicola
Xanthomendoza fallax
X. fulva

McKINLEY PARK 12 species
Caloplaca cf. crenulatella
Candelaria concolor
Hyperphyscia adglutinata
Lecanora dispersa
Parmotrema hypotropum
Phaeophyscia ciliata
P. hirsuta
P. pusilloides
Physcia millegrana
P. stellaris
Physciella chloantha
Xanthomendoza fallax

NORTH PARK VILLAGE NATURE PRESERVE 25 species
Amandinea punctata
Anisomeridium polypori
Arthonia caesia
Bacidina egenula
Caloplaca cf. crenulatella
Candelaria concolor
Candelariella reflexa
Endocarpon pusillum
Flavoparmelia caperata
Hyperphyscia adglutinata
Lecanora dispersa
Parmelia sulcata
Parmotrema hypotropum
Phaeophyscia ciliata
P. hirsuta
P. pusilloides
P. rubropulchra
Physcia adscendens
P. millegrana
P. stellaris
Physciella chloantha
Thelidium zwackhii
Trapeliopsis flexuosa
Verrucaria calkinsiana
Xanthomendoza fallax

SHERMAN PARK 15 species
Caloplaca cf. crenulatella
C. subsoluta
Candelaria concolor
Endocarpon pusillum
Flavoparmelia caperata
Hyperphyscia adglutinata
Lecanora dispersa
Phaeophyscia hirsuta
P. pusilloides
Physcia adscendens
P. millegrana
P. stellaris
Physciella chloantha
Xanthomendoza fallax
X. fulva

Transactions of the Illinois State Academy of Science
(2005), Volume 98, #3&4, pp. 123-130

received 2/17/05
accepted 6/15/05

Naturalized Callery Pear (*Pyrus calleryana* Decne.) in Illinois

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ABSTRACT

The ornamental Callery pear (*Pyrus calleryana* Decne.) is reported as a naturalized species in 66 of Illinois' 102 counties. In Lake of the Woods Forest Preserve in Champaign County, dense Callery pear thickets include individuals that range from seedlings to mature trees 20 cm in diameter at breast height. This plant has the potential to become a serious invasive pest in Illinois grasslands and open woodlands.

INTRODUCTION

Callery pear (*Pyrus calleryana* Decne., 2N = 34, Rosaceae), a small tree native to Korea and China, has been widely planted as an ornamental throughout Illinois and most of the United States. This taxon was introduced into America in the early 1900s for use along streets in cities and residential areas. Its attractive white flowers and relatively small size make it ideal for these areas. The "Bradford" cultivar was originally considered sterile, and it has been widely planted even though its limbs are susceptible to wind and ice damage.

Wild, reproducing individuals of Callery pear have been known from Lake of the Woods Forest Preserve near Mahomet in Champaign County, Illinois for more than a decade. Although Callery pear has been reported as naturalized from Du Page County, Illinois, this plant has not been considered a serious invasive plant pest in Illinois (Swink and Wilhelm 1994, Mohlenbrock 2002).

METHODS

Field searches were conducted at Lake of the Woods Forest Preserve in Champaign County, Illinois to locate naturalized individuals of Callery pear. Notes were taken on population size, individual size, fruit production, and seedling survival. Naturalized Callery pears were also sought during a drive-through survey of counties throughout the state.

Naturalized, wild-growing trees were distinguished from planted ones on the basis of their location, habitat, and growth form. If a plant showed no evidence or likelihood of being planted or tended, then it was considered to be naturalized. Nursery-grown trees

have trunks that are free of branches for a meter or more above the ground, but spontaneous individuals have branches close to the ground. In contrast to cultivated specimens, wild Callery pears tend to have a more open branching pattern, and they often are much more heavily armed with thorny spur shoots. Most of the naturalized specimens in Illinois have become established by seed, but the species sometimes spreads by sprouting from roots. The species also readily re-sprouts when it is cut. Sprouts growing from the base of a planted tree were not considered to be evidence of naturalization, but sprouts that appeared to be growing independently of any planted tree were counted as naturalized.

Voucher specimens were deposited in the Stover–Ebinger Herbarium at Eastern Illinois University (EIU). Literature searches were conducted to determine the status of this plant in Illinois and other states. Nomenclature follows Mohlenbrock (2002).

RESULTS AND DISCUSSION

Several individuals of Callery pear were reported as naturalized in Hidden Lake Forest Preserve in Du Page County, Illinois by Swink and Wilhelm (1994). These plants were growing in a disturbed area with Amur honeysuckle (*Lonicera maackii* [Rupr.] Maxim.), multiflora rose (*Rosa multiflora* Thunb.), common buckthorn (*Rhamnus cathartica* L.), black raspberry (*Rubus occidentalis* L.), and riverbank grape (*Vitis riparia* Michx.). This was the only reported location for the species in the Chicago region.

Searches in old fields at Lake of the Woods Forest Preserve near Mahomet in Champaign County, Illinois revealed thousands of individuals of Callery pear, ranging from very small seedlings to mature trees 9 m tall and 20 cm in diameter at breast height. Callery pear formed dense, impenetrable thickets whose individuals contained many thorn-like spur branches. Trees 2 m or more in height were laden with fruit.

The majority of these specimens were in an old field north of the west entrance road for Lake of the Woods Forest Preserve. A 0.5-km segment of this road was lined with 58 mature Callery pears, the oldest of which were planted in the mid-1960s; these must have served as the source of the invasion. The herbaceous vegetation of the old field was dominated by common fescue (*Festuca pratensis* Huds.) and Canada goldenrod (*Solidago canadensis* L.). Scattered individuals of white oak (*Quercus alba* L.), red oak (*Q. rubra* L.), shingle oak (*Q. imbricaria* Michx.), white ash (*Fraxinus americana* L.), and wild black cherry (*Prunus serotina* Ehrh.) were present. Naturalized Callery pears occurred elsewhere in the preserve, as far as 1.5 km from the west entrance road; these trees may have spread from other plantings in and around the preserve.

Callery pear is now a well-established member of the Illinois flora. Naturalized plants are most abundant in lawns and flowerbeds close to planted parent trees, but the seeds can be dispersed great distances by birds. Reproductive populations have become established in grassy areas, open woods, fencerows, and forest edges far from planted stock. Some plants spread by root suckers (sprouts), forming clonal thickets reminiscent of gray dogwood (*Cornus racemosa* Lam.) and white poplar (*Populus alba* L.).

The species has also been reported as naturalized in North Carolina (Nesom 2000). Vincent (2005) has reported escaped populations in 25 states and the District of Columbia.

This plant has the potential to become a major plant pest in Illinois and much of the United States.

The four specimens listed below are deposited in the Stover–Ebinger Herbarium, Eastern Illinois University, Charleston, Illinois (EIU). The collecting location is in Champaign County, Illinois at Lake of the Woods Forest Preserve, NE edge of Mahomet, Illinois, SE 1/4 section 10, T20N, R7E. Specimens were collected on October 25, 2003.

J.E. Ebinger & W.E. McClain #31539. Tree 11 m tall planted at edge of preserve road (1 of 58 planted individuals along road).

J.E. Ebinger & W.E. McClain #31542. Seedling under tree in Callery pear thicket in old field.

J.E. Ebinger & W.E. McClain #31544. Tree 8 m tall in Callery pear thicket in old field.

J.E. Ebinger & W.E. McClain #31546. Tree 8 m tall in prairie restoration.

The following other records are documented by vouchers at EIU. These are in addition to the Champaign County collections listed above, and the Du Page County record previously reported in the literature:

Bond County: John White #2004-67, October 22, 2004. NW 1/4 NW 1/4 section 2, T5N, R2W, in Royal Lake Resort. Fruiting tree 4 m tall in an abandoned field, with no planted *Pyrus calleryana* trees in the immediate vicinity. Associates: *Festuca pratensis*, *Cirsium discolor* Muhl. (Spreng.), *Tridens flavus* (L.) Hitchc., *Solidago canadensis*.

Boone County: John White #2004-23, May 12, 2004. SE 1/4 SE 1/4 section 26, T44N, R3E, in Belvidere. Seedling in a lawn beneath a planted, fruiting *Pyrus calleryana* tree. Associates: *Taraxacum officinale* Weber, *Poa pratensis* L.

Bureau County: John White #2004-35, May 18, 2004. NW 1/4 SE 1/4 section 16, T16N, R9E, in Princeton. Sprout 0.5 m tall at the edge of a lawn next to a planted, fruiting *Pyrus calleryana* tree. Associate: *Poa pratensis*.

Carroll County: John White #2004-36, May 24, 2004. NE 1/4 NW 1/4 section 25, T25N, R7E, in Shannon. Seedling in wood-chip mulch beneath a planted, fruiting *Pyrus calleryana* tree; 1 of 4 seedlings.

Cass County: John White #2004-54, July 18, 2004. SW 1/4 NE 1/4 section 15, T18N, R12W, in Beardstown. Seedling in a flowerbed beneath a planted, fruiting *Pyrus calleryana* tree; 1 of 8 seedlings. Associates: *Taraxacum officinale*, *Euonymus fortunei* (Turcz.) Hand.-Mazz, *Celtis occidentalis* L.

Champaign County: John White #2004-43, June 4, 2004. NW 1/4 NE 1/4 section 25, T19N, R8E, in Savoy. Fruiting tree 5 m tall in a weedy prairie remnant; part of a wild population of *Pyrus calleryana* along 0.9 km of railroad right-of-way, including at least 21 plants less than 1 m tall, 22 plants 1 to 2 m tall, and 141 plants taller than 2 m. Associates: *Poa pratensis*, *Oligoneuron rigidum* (L.) Small, *Solidago canadensis*, *Daucus carota* L.

Christian County: John White #2004-50, June 21, 2004. NE 1/4 NE 1/4 section 21, T11N, R1E, in Pana. Seedling in a crack in a street curb beneath a planted, fruiting *Pyrus calleryana* tree; 1 of 6 seedlings. Associates: *Oxalis stricta* L., *Poa pratensis*, *Taraxacum officinale*.

Clark County: John White #2004-26, May 15, 2004. NW 1/4 NE 1/4 section 12, T11N, R12W, 1.2 km N of Marshall. Sapling 0.4 m tall in a flowerbed next to a planted, fruiting *Pyrus calleryana* tree; 1 of approximately 20 seedlings and saplings. Associates: *Chenopodium album* L., *Galium aparine* L., *Lamium amplexicaule* L.

Coles County: John White #2004-51, June 21, 2004. NE 1/4 SW 1/4 section 20, T12N, R7E, 3 km W of Mattoon. Sapling 0.6 m tall in a flowerbed at a golf course that has many planted, fruiting *Pyrus calleryana* trees. Associates: *Hedera helix* L., *Poa pratensis*, *Lamium amplexicaule*.

Cook County: John White #2004-52, July 1, 2004. SW 1/4 SW 1/4 section 23, T42N, R12E, in Glenview. Sterile tree 2.3 m tall on the bank of a ditch (West Fork of the North Branch of the Chicago River), with no planted *Pyrus calleryana* trees in the immediate vicinity. Associates: *Bromus inermis* Leyss., *Populus deltoides* Marsh.

Crawford County: John White #2004-27, May 15, 2004. NE 1/4 SE 1/4 section 34, T7N, R12W, in Robinson. Sprout 1 m tall, growing from the stump of a volunteer tree that had been cut down in a vacant city lot. Associates: *Poa pratensis*, *Medicago lupulina* L., *Trifolium repens* L.

Cumberland County: John White #2004-66, August 20, 2004. SE 1/4 SE 1/4 section 7, T10N, R7E, in Neoga. Seedling in a lawn that has a planted, fruiting *Pyrus calleryana* tree. Associates: *Poa pratensis*, *Festuca pratensis*, *Plantago rugelii* Decne.

De Witt County: John White #2004-30, May 18, 2004. NW 1/4 NE 1/4 section 34, T20N, R2E, in Clinton. Seedling in the stairwell of a building on the city square, where several *Pyrus calleryana* trees have been planted. Associates: *Commelina communis* L., *Smilax tamnoides* L. var. *hispida* (Muhl.) Fern.

Douglas County: John White #2004-29, May 18, 2004. NW 1/4 NE 1/4 section 2, T15N, R8E, in Tuscola. Seedling in a lawn beneath a planted, fruiting *Pyrus calleryana* tree. Associates: *Poa pratensis*, *Stellaria media* (L.) Cyrillo, *Oxalis stricta*.

Edgar County: John White #2004-25, May 15, 2004. SE 1/4 SW 1/4 section 25, T14N, R12W, in Paris. Seedling in a lawn beneath a planted, fruiting *Pyrus calleryana* tree. Associates: *Poa pratensis*, *Plantago rugelii*, *Trifolium repens*.

Effingham County: John White #2004-60, August 15, 2004. SE 1/4 SE 1/4 section 20, T8N, R6E, in Effingham. Sapling 0.7 m tall in a weedy strip between two parking lots, 2 to 11 m from 2 planted, fruiting *Pyrus calleryana* trees; 1 of 4 saplings. Associates: *Lactuca saligna* L., *Daucus carota*, *Chenopodium album*, *Eragrostis pectinacea* (Michx.) Nees.

Fayette County: John White #2004-61, August 15, 2004. NW 1/4 SW 1/4 section 16, T6N, R1E, in Vandalia. Sprout 0.9 m tall in an infrequently mowed strip beside a parking lot, next to a planted, fruiting *Pyrus calleryana* tree. Associate: *Medicago lupulina*.

Ford County: John White #2004-42, May 25, 2004. NW 1/4 NW 1/4 section 35, T25N, R7E, in Sibley. Seedling in a crack in a concrete stairway along a street that has several planted, fruiting *Pyrus calleryana* trees; 1 of 3 seedlings. Associates: *Conyza canadensis* (L.) Cronq., *Taraxacum officinale*.

Franklin County: John White #2004-8, April 23, 2004. SE 1/4 NE 1/4 section 19, T5S, R3E, 4 km N of Benton. Fruiting tree 8 m tall in an abandoned field, with no planted *Pyrus calleryana* trees in the immediate vicinity; 1 of several large, reproductive individuals. Associates: *Festuca pratensis*, *Elaeagnus umbellata* Thunb., *Lonicera japonica* Thunb.

Fulton County: John White #2004-57, August 13, 2004. SE 1/4 SW 1/4 section 22, T5N, R3E, in Lewistown. Seedling in a lawn near a planted, fruiting *Pyrus calleryana* tree. Associate: *Poa pratensis*.

Greene County: John White #2004-46, June 21, 2004. SW 1/4 SW 1/4 section 25, T9N, R12W, 2 km W of Kane. Fruiting tree 7 m tall in a fenceline between a road and former pasture, with no planted *Pyrus calleryana* trees in the vicinity. Associates: *Festuca pratensis*, *Daucus carota*, *Prunus serotina*, *Maclura pomifera* (Raf.) Schneider.

Jackson County: John White #2004-11, April 24, 2004. NE 1/4 NE 1/4 section 28, T8S, R2W, 1 km N of Murphysboro. Fruiting tree 5 m tall in an abandoned field; 1 of more than 100 individuals ranging from 1 to 7 m tall; a few of the largest trees appear to have been planted. Associates: *Andropogon virginicus* L., *Solidago canadensis*, *Elaeagnus umbellata*, *Liquidambar styraciflua* L.

Jefferson County: John White #2004-13, April 24, 2004. SE 1/4 SE 1/4 section 12, T4S, R1E, 2 km S of Waltonville. Fruiting tree 4 m tall beside a road at the edge of a coal strip-mine; 1 of 2 trees, neither of which was planted. Associates: *Festuca pratensis*, *Solidago canadensis*, *Lespedeza cuneata* (Dum.-Cors.) G. Don, *Juniperus virginiana* L., *Elaeagnus umbellata*, *Ulmus americana* L.

Jersey County: John White #2004-45, June 21, 2004. SW 1/4 SW 1/4 section 21, T8N, R11W, in Jerseyville. Seedling in a lawn beneath a planted, fruiting *Pyrus calleryana* tree; 1 of 5 seedlings. Associates: *Poa pratensis*, *Oxalis stricta*, *Plantago lanceolata* L., *Plantago rugelii*.

Jo Daviess County: John White #2004-21, May 8, 2004. NW 1/4 NE 1/4 section 11, T27N, R4E, in Stockton. Seedling in a lawn beneath a planted, fruiting *Pyrus calleryana* tree; 1 of 3 seedlings. Associates: *Poa pratensis*, *Taraxacum officinale*.

Johnson County: John White #2004-64, August 20, 2004. NW 1/4 SE 1/4 section 4, T13S, R3E, in Vienna. Seedling in shredded bark mulch beneath a planted, fruiting *Pyrus calleryana* tree. Associate: *Prunus serotina*.

Kane County: John White #2004-7, April 22, 2004. NE 1/4 SW 1/4 section 13, T42N, R6E, 2 km ENE of Hampshire. Flowering tree 3 m tall in an abandoned field, about 1 km from a nursery that has many planted *Pyrus calleryana* trees. Associates: *Bromus inermis*, *Lonicera maackii*, *Rosa multiflora*, *Rhamnus cathartica*.

Knox County: John White #2004-59, August 13, 2004. SE 1/4 NE 1/4 section 29, T11N, R2E, in Knoxville. Seedling in a lawn beneath a planted, fruiting *Pyrus calleryana* tree. Associate: *Poa pratensis*.

La Salle County: John White #2004-5, April 20, 2004. NE 1/4 NW 1/4 section 26, T32N, R1E, at the W edge of Tonica. Sprout 1 m tall growing from the snag of a mature tree that had been cut down in a fencerow; 1 of 6 adventive trees along 100 m of fenceline bordering a nursery that has many planted and adventive *Pyrus calleryana* trees. Associates: *Bromus inermis*, *Melilotus alba* Medic., *Asclepias syriaca* L.

Lawrence County: John White #2004-28, May 15, 2004. SE 1/4 SW 1/4 section 36, T4N, R12W, in Lawrenceville. Sapling 0.7 m tall in an untended corner of a cemetery that has many planted, fruiting *Pyrus calleryana* trees. Associates: *Toxicodendron radicans* (L.) Kuntze, *Poa pratensis*, *Glechoma hederacea* L.

Lee County: John White #2004-38, May 25, 2004. NE 1/4 NW 1/4 section 29, T22N, R9E, in Dixon. Sapling 0.8 m tall along a road bordering a golf course that has many planted *Pyrus calleryana* trees; 1 of 2 saplings. Associates: *Alliaria petiolata* (Bieb.) Cavara & Grande, *Toxicodendron radicans*, *Parthenocissus quinquefolia* (L.) Planch., *Urtica gracilis* Ait.

Livingston County: John White #2004-41, May 25, 2004. NE 1/4 NW 1/4 section 27, T28N, R5E, in Pontiac. Seedling in the gravel mulch of an ornamental border that has planted, fruiting *Pyrus calleryana* trees.

Logan County: John White #2004-31, May 18, 2004. NW 1/4 NW 1/4 section 32, T20N, R2W, in Lincoln. Sprout 1 m tall from a tree that had been broken off in the bed of a ditch. Associates: *Ambrosia artemisiifolia* L., *Medicago lupulina*, *Plantago lanceolata*.

McHenry County: John White #2004-16, May 4, 2004. NW 1/4 SE 1/4 section 21, T43N, R6E, 5.2 km S of Union. Sprout 0.4 m tall in the mowed part of an old tree nursery, within 50 m of dozens of old, planted *Pyrus calleryana* trees. Associate: *Bromus inermis*.

McLean County: John White #2004-3, April 20, 2004. NE 1/4 SW 1/4 section 17, T24N, R2E, at the N edge of Normal. Flowering tree 3 m tall in a fallow area in a highway interchange; 1 of 2 *Pyrus calleryana* trees that are obviously adventive among several others that were planted. Associates: *Bromus inermis*, *Solidago canadensis*, *Securigera varia* (L.) Lassen.

Macon County: John White #2004-2, April 13, 2004. SW 1/4 SW 1/4 section 24, T17N, R2E, 5.7 km SW of Oreana. Flowering tree 3 m tall in a brushy highway right-of-way; 1 of hundreds of adventive *Pyrus calleryana* plants of all size classes along a 1.2-km stretch of highway, spread from trees that were planted in the immediate vicinity. Associates: *Bromus inermis*, *Elaeagnus umbellata*, *Prunus serotina*.

Macoupin County: John White #2004-47, June 21, 2004. SW 1/4 NE 1/4 section 28, T10N, R7W, in Carlinville. Seedling in gravel mulch next to a building near a row of planted, fruiting *Pyrus calleryana* trees; 1 of 6 seedlings. Associate: *Portulaca oleracea* L.

Madison County: John White #2004-44, June 21, 2004. NW 1/4 NW 1/4 section 35, T6N, R10W, in Godfrey. Sterile, adventive tree 2.4 m tall next to a row of planted, fruiting *Pyrus calleryana* trees in a highway right-of-way. Associates: *Festuca pratensis*, *Lactuca serriola* L., *Calystegia sepium* (L.) R. Br.

Marion County: John White #2004-65, August 20, 2004. SW 1/4 NE 1/4 section 11, T2N, R2E, in Salem. Seedling in gravel mulch beneath a planted, fruiting *Pyrus calleryana* tree; 1 of 3 seedlings. Associates: *Celtis occidentalis*, *Digitaria sanguinalis* (L.) Scop., *Chamaesyce prostrata* (Ait.) Small.

Marshall County: John White #2004-34, May 18, 2004. SE 1/4 NW 1/4 section 25, T30N, R3W, in Lacon. Seedling in an unmowed part of a lawn next to a planted, fruiting *Pyrus calleryana* tree. Associates: *Phalaris arundinacea* L., *Glechoma hederacea*, *Morus alba* L.

Mason County: John White #2004-53, July 18, 2004. SE 1/4 NE 1/4 section 18, T20N, R9W, in Bath. Sprout 0.3 m tall in a mowed lawn at the edge of a cemetery that has several planted, mature *Pyrus calleryana* trees. Associates: *Poa pratensis*, *Leptoloma cognatum* (Schult.) Chase.

Massac County: John White #2004-62, August 19, 2004. NE 1/4 NW 1/4 section 5, T16S, R5E, in Metropolis. Seedling in a lawn beneath a planted, fruiting *Pyrus calleryana* tree. Associates: *Poa pratensis*, *Taraxacum officinale*.

Menard County: John White #2004-57, August 13, 2004. NE 1/4 SW 1/4 section 14, T18N, R7W, in Petersburg. Seedling in a flowerbed that has several planted, fruiting *Pyrus calleryana* trees; 1 of more than 20 seedlings.

Monroe County: John White #2004-69, October 23, 2004. NE 1/4 NE 1/4 section 25, T2S, R10W, in Waterloo. Seedling in bare soil beneath a planted, fruiting *Pyrus calleryana* tree; 1 of 3 seedlings. Associates: *Prunus serotina*, *Celtis occidentalis*, *Morus alba*.

Montgomery County: John White #2004-48, June 21, 2004. SW 1/4 SW 1/4 section 32, T9N, R5W, in Litchfield. Sapling 1.1 m tall in an ornamental hedge next to a planted, fruiting *Pyrus calleryana* tree; 1 of more than 20 saplings. Associates: *Poa pratensis*, *Aster pilosus* Willd., *Lactuca serriola*.

Ogle County: John White #2004-37, May 25, 2004. SE 1/4 SE 1/4 section 27, T24N, R9E, in Mount Morris. Seedling in gravel along the foundation of a building, 11 m from a planted, fruiting *Pyrus calleryana* tree. Associate: None.

Peoria County: John White #2004-33, May 18, 2004. SE 1/4 NE 1/4 section 9, T8N, R8E, in Peoria. Fruiting tree 4 m tall on the bank of the Illinois River, next to a park that has many planted *Pyrus calleryana* trees. Associates: *Acer saccharinum* L., *Ulmus pumila* L.

Perry County: John White #2004-12, April 24, 2004. SW 1/4 NE 1/4 section 34, T6S, R2W, 5 km SW of DuQuoin. Fruiting tree 4 m tall in a thicket at the edge of a cemetery in a coal strip-mine; 1 of 2 trees, neither of which was planted. Associates: *Elaeagnus umbellata*, *Rubus allegheniensis* Porter, *Lonicera japonica*, *Sassafras albidum* (Nutt.) Nees, *Quercus imbricaria*.

Piatt County: John White #2004-1, April 13, 2004. NW 1/4 NW 1/4 section 6, T18N, R6E, 2 km N of Monticello. Flowering tree 4 m tall in a fenceline bordering a highway right-of-way, near planted, mature *Pyrus calleryana* trees. Associates: *Bromus inermis*, *Solidago canadensis*, *Melilotus alba*.

Pope County: John White #2004-63, August 20, 2004. SW 1/4 SW 1/4 section 19, T13S, R7E, in Golconda. Sprout in a flower bed surrounding a planted, fruiting *Pyrus calleryana* tree; 1 of more than 200 sprouts and seedlings. Associates: *Celtis occidentalis*, *Ulmus americana*.

Randolph County: John White #2004-70, October 23, 2004. NW 1/4 SW 1/4 section 19, T7S, R6W, in Chester. Seedling in a lawn near a *Pyrus calleryana* tree; 1 of 4 seedlings. Associates: *Poa pratensis*, *Trifolium repens*, *Taraxacum officinale*.

St. Clair County: John White #2004-68, October 23, 2004. NE 1/4 NW 1/4 section 11, T1S, R9W, 1 km ENE of Millstadt. Fruiting tree 4 m tall in a roadside fencerow, across a highway from a planted *Pyrus calleryana* tree. Associates: *Juglans nigra* L., *Helianthus divaricatus* L., *Cornus racemosa*.

Sangamon County: John White #2004-56, August 12, 2004. NE 1/4 SW 1/4 section 28, T15N, R5W, 8.5 km SSW of the center of Springfield. Fruiting tree 3 m tall in a 0.5-hectare abandoned field; 1 of 6 mature trees and several saplings, none of which appears to have been planted. Associates: *Poa pratensis*, *Solidago canadensis*, *Elaeagnus umbellata*.

Scott County: John White #2004-55, July 18, 2004. NE 1/4 NW 1/4 section 5, T14N, R 13W, 1.6 km SW of Oxville. Sapling 1.3 m tall in a thicket at the edge of a lawn that has a planted, fruiting *Pyrus calleryana* tree. Associates: *Cercis canadensis* L., *Ulmus americana*, *Solidago canadensis*, *Poa pratensis*.

Shelby County: John White #2004-49, June 21, 2004. NE 1/4 NE 1/4 section 13, T11N, R3E, in Shelbyville. Seedling in gravel mulch bordering a parking lot, near a row of planted, fruiting *Pyrus calleryana* trees; 1 of 4 seedlings. Associates: *Lindernia dubia* (L.) Pennell, *Chamaesyce maculata* (L.) Small, *Digitaria sanguinalis*.

Stark County: John White #2004-40, May 25, 2004. NE 1/4 NW 1/4 section 25, T14N, R7E, in Bradford. Sprout 0.4 m tall in a flowerbed next to a planted, fruiting *Pyrus calleryana* tree; 1 of 2 sprouts and approximately 10 seedlings. Associates: *Asclepias syriaca*, *Rubus occidentalis*, *Lactuca serriola*.

Stephenson County: John White #2004-22, May 10, 2004. NE 1/4 SW 1/4 section 6, T26N, R8E, in Freeport. Seedling in a flowerbed next to a planted, fruiting *Pyrus calleryana* tree. Associates: *Taraxacum officinale*, *Polygonum arenastrum* Boreau.

Tazewell County: John White #2004-32, May 18, 2004. SW 1/4 NE 1/4 section 20, T25N, R3W, in Morton. Seedling in a crack in the pavement of a parking lot next to a planted, fruiting *Pyrus calleryana* tree; 1 of 4 seedlings. Associate: None.

Union County: John White #2004-10, April 24, 2004. NE 1/4 SW 1/4 section 20, T12S, R1W, in Anna. Seedling in a weedy area between a parking lot and a building, next to a planted, fruiting *Pyrus calleryana* tree. Associates: *Prunus serotina*, *Ulmus americana*.

Vermilion County: John White #2004-24, May 15, 2004. NE 1/4 NW 1/4 section 8, T19N, R12W, 3.1 km ENE of Oakwood. Sapling 1 m tall in a powerline right-of-way; 1 of 3 saplings within 8 to 10 m of a planted, fruiting *Pyrus calleryana* tree. Associates: *Festuca pratensis*, *Poa pratensis*, *Daucus carota*, *Carex blanda* Dewey.

Washington County: John White #2004-14, April 24, 2004. SW 1/4 NW 1/4 section 18, T1S, R2W, in New Minden. Sapling 0.7 m tall at the edge of a cemetery that has several planted, flowering *Pyrus calleryana* trees. Associates: *Poa pratensis*, *Juniperus virginiana*.

Whiteside County: John White #2004-39, May 25, 2004. NE 1/4 NE 1/4 section 28, T21N, R7E, in Sterling. Seedling in a crack between a sidewalk and a bridge abutment, next to a row of planted, fruiting *Pyrus calleryana* trees. Associate: *Parietaria pensylvanica* Muhl.

Will County: John White #2004-15, May 4, 2004. NE 1/4 NW 1/4 section 6, T33N, R13E, 5.5 km SW of Monee. Flowering tree 6 m tall in a fencerow along a road, with no planted *Pyrus calleryana* trees in the immediate vicinity. Associates: *Prunus serotina*, *Toxicodendron radicans*, *Poa pratensis*.

Williamson County: John White #2004-9, April 23, 2004. NE 1/4 NE 1/4 section 19, T9S, R3E, in Marion. Seedling beneath a planted, fruiting *Pyrus calleryana* tree in a parking lot; 1 of 4 seedlings.

Winnebago County: John White #2004-6, April 22, 2004. SW 1/4 NW 1/4 section 9, T43N, R2E, at the S edge of Rockford. Flowering tree 4 m tall in a fallow area in a highway interchange, with no planted *Pyrus calleryana* trees in the immediate vicinity. Associates: *Bromus inermis*, *Ulmus pumila*, *Elaeagnus umbellata*, *Juniperus virginiana*.

Woodford County: John White #2004-4, April 20, 2004. SE 1/4 section 30, T26N, R2E, 1 km NW of Kappa. Sprout 0.6 m tall in a mowed highway right-of-way, 3 m from the nearest planted *Pyrus calleryana* tree; 1 of 2 sprouts. Associates: *Bromus inermis*, *Melilotus alba*.

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Transactions of the Illinois State Academy of Science
(2005), Volume 98, #3&4, pp. 131-138

received 9/14/04
accepted 1/22/05

Method Development for Determination of Di(2-Ethylhexyl)Phthalate and its Metabolite Mono(2-Ethylhexyl)Phthalate by Reversed-Phase Liquid Chromatography

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ABSTRACT

Di(2-ethylhexyl)phthalate (DEHP) is a benzenedicarboxilate ester which is the most widely used plasticizer to soften resins. DEHP is hydrolyzed into what many believe to be its toxic metabolite, mono(2-ethylhexyl)phthalate (MEHP), by lipase enzymes in the gastrointestinal tract. The reversed-phase high-performance liquid chromatographic method to determine the presence of DEHP and MEHP simultaneously was developed. Using several methodological variables including controlled pH of the mobile phase, inclusion of different solvents for the sample, and introduction of an ion-pairing reagent, the best method for quantification of both chemicals was determined to be linear gradient elution. The estimated detection limits were determined to be 3 and 2 ppm for DEHP and MEHP, respectively. The developed method was found to be simple and precise, with a high degree of accuracy for determining DEHP and its metabolite.

INTRODUCTION

According to I. Paris et. al. (2003), Di(2-ethylhexyl)phthalate (DEHP) is one of the most widely used plasticizers for polyvinylchloride (PVC). Lundberg and co-workers (1992) estimated the world production of DEHP at approximately 1 million tons per year. Hill et. al. (2001) explains that DEHP essentially acts as a lubricant between the polymeric chains and causes the flexibility and softness of the plastic at low temperatures. Both Paris et. al. (2003) and Lundberg et. al. (1992) conclude that the DEHP content in PVC can be up to 40% (w/w). As a result of the plasticity and durability provided by DEHP, PVC is used in many applications such as construction material, waterproof clothing, food-wrapping material, industrial tubing, toys, medical devices (catheters, blood storage bags, tubing), cosmetics, and dieletric fluid in condensers, as stated by Lundberg et. al., (1992) Arcadi et. al (1998), and Kato et. al (2003). Despite these often-desired characteristics, concerns about the interactions between the plastic and the contained materials, such as food, blood, and pharmaceuticals are well documented. These interactions include sorption, the uptake of the containing material by the plastic, and leaching, the

release of plastic additives into the containing material, as described by Jenke (2003). Various concentrations have been found in food due to the DEHP leaching from packaging. Levels of 13.4-91.5 mg/kg (dry weight) have been reported in lung tissue of patients that received transfusions. Notably, Lundberg et. al (1992) found that solubility of DEHP in blood is significantly better than in water.

A significant number of studies have described the toxicity of DEHP in animals and thus raised concern of its effects on humans. The Environmental Protection Agency (EPA) lists DEHP in the B2 Group of probable human carcinogens. DEHP can enter the body in several ways. First, DEHP leaches from PVC plastic bags into stored blood products at an average rate of 0.25 mg/100ml/day at 4 °C. This means that during an entire body exchange transfusion of 20-day stored blood, the patient gets about 4 mg/kg of DEHP over a period of a few hours, as documented by Curto and Thomas (1981). Second, the World Health Organization (WHO) (1996) states that it can also leach from plastic wrapping around fat-containing foods such as milk, cheese, and margarine, providing a daily adult dose of about 200 μg. Also, Arcadi and co-workers (1998) found that DEHP can accumulate in neonates via mother's milk. Lastly, patients undergoing kidney dialysis are exposed to approximately 90 mg of DEHP per treatment, according to the WHO (1996). A. Francis (1993) established a reference dose (RfD) for chronic and sub-chronic exposure at 0.02 mg/kg/day; the lowest-observed-adverse-effect level (LOAEL) is 19 mg/kg/day.

Determination techniques explored by Marin and Migallon (2002) such as nuclear magnetic resonance spectrometry, ultraviolet (UV) spectrometry, and UV desorption-mass spectrometry are very useful when the concentrations of phthalates are high. Some chromatographic methods determining trace levels of plasticizers have been used together with a preliminary extraction/concentration step prior to analysis, mostly for environmental applications. However, the underlying theme from a number of studies, including that of Cai, Jiang, and Liu (2003), is that a sensitive, simple, and effective method for the determination of DEHP in environmental and biological samples is still necessary. The developed method for simultaneous determination of DEHP and MEHP by gradient elution HPLC is short and does not require the use of any additives to the mobile phase.

MATERIALS AND METHODS

Instrumentation

The project was conducted on the Agilent 1100 Series Liquid Chromatography System consisting of a vacuum degasser, quarternary pump, automatic autosampler, and variable wavelength UV detector. The Alltech Alltima C_{18}-LL column was 150 mm long with 4.6 mm internal diameter. It was packed with C_{18} bond silica particles of the size 5μ. The UV absorbance maxima of DEHP and MEHP were determined using Hitachi V-2000 UV-Vis Spectrophotometer. All the standard solutions were prepared using the Mettler Toledo AG204 Delta Range analytical balance. All of the pH measurements were performed on a pH meter with a glass electrode (Atlorion PerpHect LogRMeter, Beckman Instruments Combination Electrode). Lastly, the robustness of the method was verified on Dry Lab software.

Chemicals and Reagents

The mobile phase consisted of acetonitrile (ACN) (Fisher Scientific) and deonized (DI) water. Among the other chemicals used in the experiment were sodium phosphate, monobasic (Aldrich Chemical Company, INC.); phosphoric acid 85% (Mallinckrodt); sodium acetate (Aldrich Chemical Company, INC.); acetic acid (J. T. Baker Chemical Co.); tetrabutylammonium bromide (Aldrich Chemical Company, INC.); and cetyltrimethylammonium bromide (Fischer Scientific). The phthalate esters, di(2-ehtylhexyl)phthalate and mono(2-ethylhexyl)phthalate, were obtained from TCI America.

Three stock solutions of phthalate esters were prepared and their exact mass concentration was determined using the analytical balance. First, a stock solution of 277.7 ppm DEHP in 47.37% ACN was prepared. The second stock solution consisted of 425.7 ppm MEHP in 47.37% ACN while the third was a mix of both, DEHP and MEHP containing 151.5 ppm of DEHP and 193.4 ppm of MEHP. Samples of the appropriate concentration were diluted in first set of dilutions based on the following equation:

$$X_{esther}[ppm] = \frac{m_{stock}[g] \times x_{esther}[ppm]}{m_{stock}[g] + m_{solvent}[g]}$$

To minimize human error, a second set of dilutions that were used to determine the detection limit was done by manipulating the injected volumes.

Column Preparation

The C_{18} column was washed before every use with different strength of ACN to assure the elution of any species retained in the column. This was done by eluting the column for 30 minutes with 30%, 50%, and 80% ACN solutions. When buffers were used, the column was washed for an additional 30 minutes after every use with pure 70% ACN solution. In addition, when ion pairing reagent was used the column was washed after every use with 70% ACN for 60 minutes. During the last portion of the project the column was regenerated after every injection for 20 minutes using the initial concentration of ACN (5%) in the gradient elution.

UV Detector Optimization

The absorption spectra of DEHP and MEHP were recorded. Both compounds have similar absorbance with maximum absorbance for MEHP to be at the wavelength 235.2 ηm and for DEHP at 233 ηm. The wavelength of 235 ηm was found to be the optimal condition in this experiment.

RESULTS AND DISCUSSION

Using a high concentration (80%) of ACN in water as a mobile phase, the less polar DEHP was eluted in over 45 minutes following the more polar MEHP. A large capacity factor (k) resulted in a broad peak, which decreased detection sensitivity. The capacity factor is a parameter which indicates how much time the analyte spends in the stationary phase with respect to the mobile phase. MEHP was almost unretained due to its relative higher polarity. Decreasing polarity of the mobile phase helped to delay its retention, but also prolonged the retention of DEHP, which was unsatisfactory due to an even bigger broadness of its peak.

Several selecting parameters were tested to optimize resolution including effect of pH, the role of ion-pairing reagent, combined effects of ion-pairing reagent and pH, and the type of ion-pairing reagent.

Effects of pH of Mobile Phase

In an attempt to control ionization of MEHP, a buffer was introduced into the mobile phase. At low pH, MEHP is expected to be in the non-ionic form, and therefore behave more hydrophobic and retain on the stationary phase for longer time. The change in pH of the mobile phase was not expected to interfere with the retention time of DEHP. Therefore, it was believed that both species would elute in reasonably short time after the flow rate was increased. First, the 80% ACN mobile phase was prepared. After the addition of potassium phosphate buffer a visible precipitation was observed. At 70% ACN no precipitation was found, therefore the mobile phase with buffer of this strength was prepared. The influence of the phosphate buffer on MEHP gave a satisfactory result, increasing its retention time from 1.1 minute to 4.3 minutes with a sharp, tall, and symmetric peak. The retention time for DEHP unexpectedly moved from 16.7 to 42.7 minutes giving very broad peak. The flow of the mobile phase was increased from 1.00 to 1.25 ml/min to speed up the elution of MEHP and DEHP. However, even though the retention time of DEHP decreased to 34.2 minutes, this approach did not lead to a satisfactory result. DEHP was still a late eluter and the retention time for MEHP moved to 3.5 minutes, which didn't leave enough space for the unretained species to increase the flow rate even more and not to have MEHP eluted unretained.

Role of Presence of Ion-Pairing Reagent (IPR)

Tetrabutylammonium bromide (TBAB) was introduced into the mobile phase. MEHP was expected to interact with TBAB loaded on the stationary phase and therefore resulting in longer retention time. Also, a decrease in retention time of DEHP was expected due to its high hydrophobicity. The influence of mobile phase of various concentrations of TBAB was examined up to 20 mM of the TBAB. The retention time for MEHP increased from the original 1.1 minutes to 3.4 minutes and that of DEHP changed only slightly from 16.7 minutes to 17.5 minutes, which was somewhat unexpected.

Combined Effects of pH and TBAB

Since the introduction of a buffer and ion-pairing reagent produced unexpected results, the combination of both was examined for possible a synergistic effect. Mobile phase of 15 mM TBAB and 15 mM acetic acid buffer, adjusted at pH 5.03, was prepared. No synergistic effect was manifested by the results in retention times of both species.

Effects of Type of Ion-Pairing Reagent

Introducing a stronger ion-pairing reagent was a promising idea because the previously used ion-pairing reagent, tetrabutylammonium bromide, has four C-4 aliphatic chains which may not retain strongly on the stationary phase. Therefore, its dispersion interaction was not strong enough to retain TBAB on the column. A mobile phase containing cetyltrimethylammonium bromide (CTMAB) was used together with acetic buffer at pH 4.93. The hydrophobic chains of the CTMAB interact by dispersion force with the C_{16} chain of CTMAB and were therefore retained strongly by the C_{18} column. Since CTMAB is expected to retain strongly on the column and due to the difficulty of washing it form

the stationary phase, a maximum of 10 mM CTMAB was tested. Again, the retention times of both species were not sensitive to this new approach.

Linear Gradient Elution

DEHP and MEHP had a wide retention range, which implies that they were of very different polarities. DEHP, the late eluter, had a large capacity factor which resulted in band broadening. The problem of wide differences in retention between MEHP and DEHP can be solved with the use of gradient elution. Thus, introduction of gradient elution was not only expected to reduce the retention range between DEHP and MEHP, but also to enrich the concentration of impurities in both water and acetonitrile. This is important because these impurities may interfere with the determination of trace amounts of DEHP and MEHP due to baseline noise. The HPLC equipment was programmed to increase the percentage of ACN in the mobile phase from 5 to 100 % over the time of 60 minutes. Figure 1 shows that the retention range decreased significantly, with very sharp, narrow, and symmetrical peaks.

This method was optimized by adjusting the gradient time. The gradient time of 10 minutes showed the most favorable results regarding both the retention times and economic considerations, which are discussed further. MEHP eluted at 6.8 minutes and DEHP at 9.2 minutes (Figure 2), with sharp symmetrical peaks, favorable for good quantification.

Sensitivity Optimization under Gradient Elution

The default setting for ultra violet (UV) detector for maximum sensitivity was 210 nm. A series of samples was studied for the optimal wavelength conditions of the UV detector at 235 nm and 210 nm. As expected, the areas of the five different species detected at 210 nm increase. The area of DEHP increased 2.58 times and the area of MEHP 1.34 times, which justified setting the detector to this wavelength. However, some unidentified species emerged in the chromatograms with a significantly large peak area. These species can be recognized by their retention times. The peak with retention time of 2.4 minutes showed an increase in sensitivity of 4.6 times, which would interfere with the determination of detection limit at this wavelength. The decision to stay on the wavelength of 235 nm was also confirmed by statistical analysis (Table 1). The regression coefficient for DEHP measurements at 210 nm exhibits decreased linearity.

Limit of Quantitation

The smallest concentration of DEHP that could be quantitatively determined with high precision was 3 ppm. The limit of quantitation for MEHP was 2 ppm. The limits of detection for both species were calculated as three times the baseline noise.

SUMMARY

The developed linear gradient HPLC method exhibits a certain simplicity, which makes this method economically favorable and easily transferable among laboratories. The quantitation of both phthalates with elution times less than ten minutes is economical regarding both chemical usage and time-efficiency.

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Figure 1: Linear Gradient elution. (Gradient time: 20minutes, Gradient range: 5-100% ACN, Flow rate: 1.0 Ml/min) Retention time of MEHP: 15.686 min, Retention time of DEHP: 22.721 min.

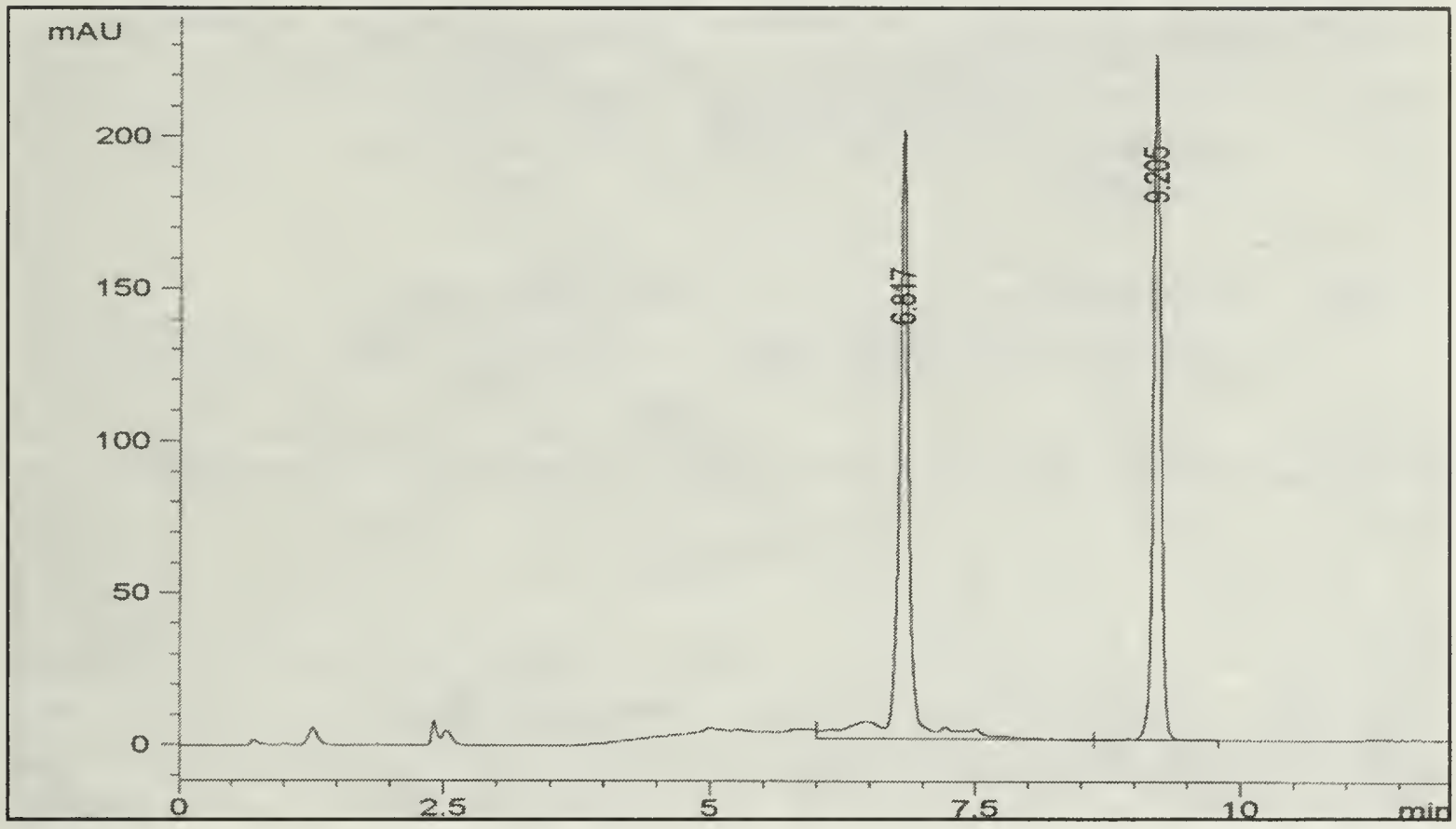

Figure 2: Linear Gradient elution. (Gradient time: 5minutes, Gradient range: 5-100% ACN, Flow rate: 1.0 Ml/min) Retention time of MEHP: 6.817 min, Retention time of DEHP: 9.205 min.

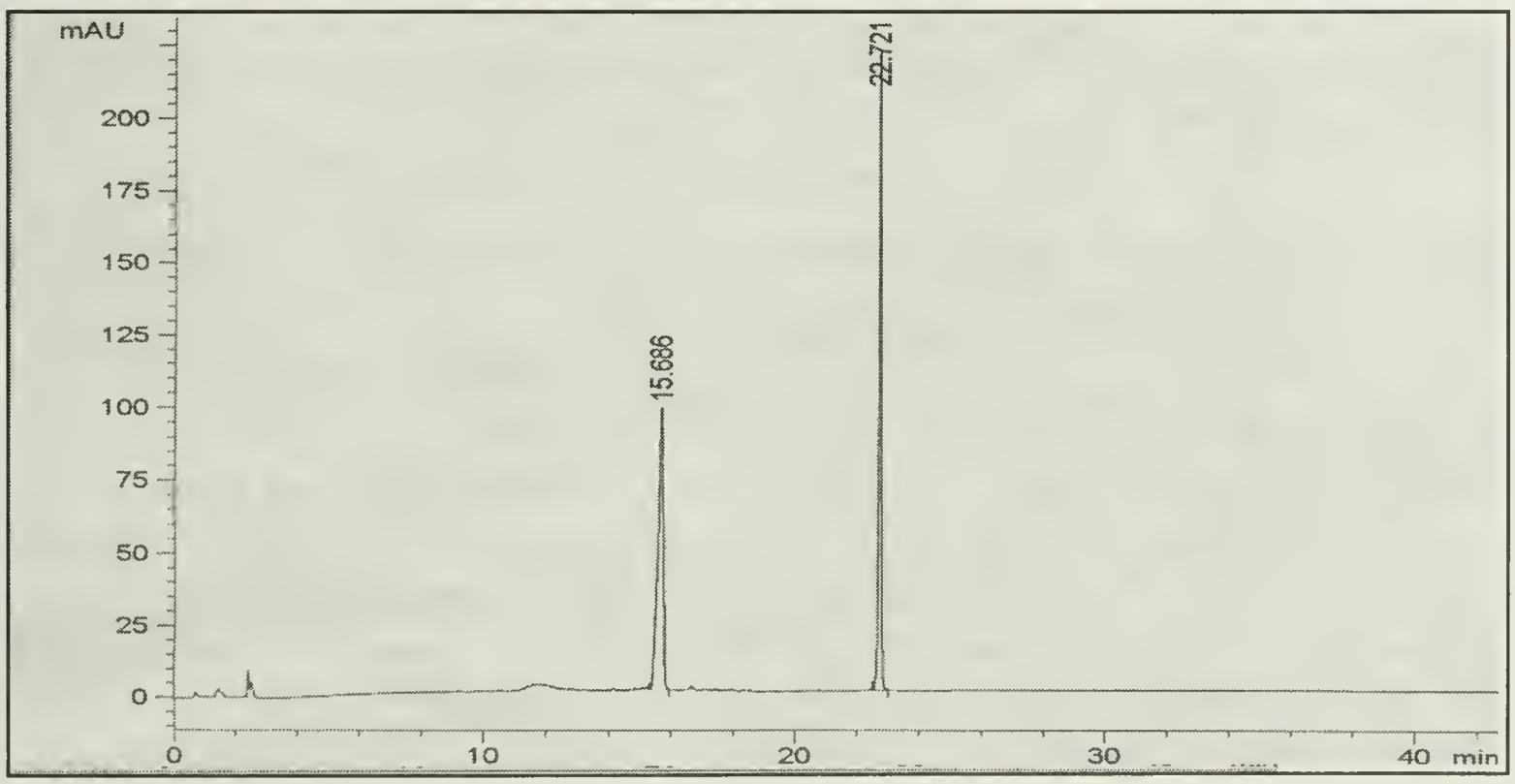

Table 1: The comparison of the regression coefficients for DEHP and MEHP at the wavelengths of 210 ηm and 235 ηm.

	Wavelength: 235ηm	Wavelength: 210ηm
DEHP	31 measurements $y = 0.6892*Area - 0.5527$ [ppm] $R^2 = 0.9938$	11 measurements $y = 0.023227*Area - 3.0164$[ppm] $R^2 = 0.8735$
MEHP	38 measurements $y = 0.0568*Area - 0.8511$[ppm] $R^2 = 0.9958$	12 measurements $y = 0.021248*Area - 4.74509$[ppm] $R^2 = 0.9990$

Transactions of the Illinois State Academy of Science
(2005), Volume 98, #3&4, pp. 139-144

received 4/4/05
accepted 12/8/05

Systematic Studies on Column Ruggedness when Separating Weak Acids Using Reversed-Phase Liquid Chromatography

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ABSTRACT

Ruggedness of three reversed-phase C_{18} columns of different brands and with different sizes was investigated for the separation of an acidic sample containing 4-hydroxybenzoic acid, acetylsalicylic acid, benzoic acid, 4-methoxyphenyl acetic acid, 3,5-dinitrobenzoic acid, o-toluic acid and phenylpropionic acid. These columns included Alltech Altima C_{18} (25 × 0.46 cm), Burdick & Jackson C_{18} (25 × 0.46 cm) and Alltech Nucleosil C_{18} (15 × 0.46 cm).

The optimum separation conditions were found to be under mobile phase conditions of 30% acetonitrile buffered with 15 mM of both sodium phosphate monobasic and sodium acetate at pH 3.01 when using Alltech Altima C_{18}. Identical separations with subsequent improvement in column efficiency were observed with Burdick & Jackson C_{18} and Alltech Nucleosil C_{18} columns when sodium acetate buffer concentration increased to 70 mM with re-adjusting solvent strength to 20% acetonitrile. This improvement in peak shape and column ruggedness resulted from deactivating the secondary interactions between acids studied and free silanols of silica base of the stationary phases.

INTRODUCTION

Column ruggedness measures the degree of reproducibility of the test results obtained by the analysis of *same* sample under a variety of columns. It plays an important role in the robustness of the developed high performance liquid chromatographic (HPLC) method when columns from different venders are used or when a method is transferred from one lab to another. For example, an HPLC method for the quantitation of an active ingredient in a pharmaceutical product is developed in United States and transferred to another lab in Japan. The major setback in the reproducibility of the developed method is the use of columns from different venders (Heyden, et al., 1996).

The last 10 years have shown remarkable progress in the quality and reproducibility of HPLC columns. In spite of the progress and safeguards put into place, column ruggedness is still a major concern in the field of high performance liquid chromatography.

Concerns still exist in the heavily regulated industries (pharmaceutical, environmental analysis) when columns from different venders and even from the same vender but different batches may have an adverse effect on method ruggedness (Kateman, et al., 1993 and Snyder, et al., 1997). For this reason, a developed method requires testing multiple columns from different venders when the method is tested for validation. The objective of this study is to establish a common ground to improve ruggedness of reverse-phase columns. This study is limited to a sample of weak acids and columns of C_{18} type.

MATERIALS AND METHODS

Instrumentation

The HPLC system used consisted of a Spectra Physics SP 8800 ternary pump with a Spectra Physics 100 variable wavelength detector, a Hewlett Packard 3390A integrator and a Rheodyne sample injector (model 7715i, Cotati, CA). The Alltech Altima C_{18} (25 x 0.46 cm, 5 µm) and Alltech Nucleosil C_{18} (15 x 0.46 cm, 5 µm) columns were purchased from Alltech Associates, Deerfield, Illinois, (USA). Burdick and Jackson C_{18} column (25 x 0.46 cm, 5 µm) was purchased from Burdick & Jackson, Muskegon, MI (USA). All pH measurements were performed with ATI Orion model 310 pH meter. The flow rate was maintained at 1.0mL/ min and the detector wavelength was set at 254 nm. All separations were conducted under ambient temperature.

Chemicals and Reagents

Acetonitrile and sodium acetate were obtained from Fisher Scientific Company. Benzoic acid, 4-hydroxybenzoic acid, 3,5-dinitrobenzoic Acid, 4-methoxyphenyl acetic acid, phenylpropanoic acid and sodium phosphate were obtained from Aldrich Chemical Company, Inc. Acetylsalicylic acid was obtained from Acros Organics while o-toluic acid was obtained from Eastman Kodak Co. All organic solvents used were of HPLC grade while other reagents were of ACS grade.

The mobile phase used consisted of 15 mM sodium acetate ($NaCH_3COO$) and 15 mM sodium phosphate monobasic (NaH_2PO_4) . It was adjusted to the desired pH with acetic acid and phosphoric acid and filtered through a 0.45 µm membrane filter (Millipore Corporation, Massachusetts, USA). All samples used were prepared in 50% acetonitrile (ACN).

RESULTS AND DISCUSSION

Different studies were conducted to optimize mobile phase strength and separation conditions using Alltech Altima C_{18} column. At the optimum conditions of 30% ACN, separation of sample components was tested at different pH values between 2.90 and 4.50. Poor resolution was observed between 4-methoxyphenyl acetic acid and 3,5-dinitrobenzoic acid at pH 3.50, between acetylsalicylic acid and 4-methoxyphenyl acetic acid at pH 4.52, and between benzoic acid and 4-methoxyphenyl acetic acid at pH 2.90 (Table 1). DryLab© software simulated pH 3.01 as the optimum mobile phase acidity. The simulated retention times were found in a good agreement with the experimental results at pH 3.01 with the exception of 3,5-Dinitrobenzoic acid (Table 2).

When the optimum conditions for the Alltech Altima C_{18} column were tested on Alltech Nucleosil C_{18} and Burdick and Jackson C_{18} columns, poor resolutions were observed with much shorter run times (Figure 1). These results could be related to the differences in column efficiencies as well as the significance of secondary interactions between the sample components and the silanols on the silica base of the three stationary phases. To deactivate these interactions, concentration of acetate buffer salt in the mobile phase was increased from 15 mM to 30 mM. A significant improvement in the resolution with much narrower peaks was obtained with 30% ACN containing 30 mM $NaCH_3COO$ and 15 mM of NaH_2PO_4 at pH 3.01. The differences in the resolution between the three columns studied minimized, but the differences in run times still existed. The latter was related to the differences in carbon loading of the three columns studied. This was confirmed when the solvent composition of the mobile phase was reduced to 20% ACN while maintaining pH 3.01. Separations on Alltech Nucleosil C_{18} and Burdick and Jackson C_{18} columns were found identical with the exception of some tailing in the late eluting peaks. To overcome this problem, concentration of acetate buffer was increased gradually while maintaining solvent strength and pH of the mobile phase unchanged. A significant improvement in the peak shape was obtained when 70mM sodium acetate was used (Figures 2 and 3).

These observations concluded that column ruggedness could be significantly improved when separating weak acids by simply deactivating interactions of the acids with silanols on the silica base of the stationary phase and by re-adjusting mobile phase solvent strength. In this study, this was accomplished by using a mobile phase of 20% ACN buffered with 70mM of $NaCH_3COO$ and 15mM NaH_2PO_4 at pH 3.01 for columns Alltech Nucleosil C_{18} and Burdick and Jackson C_{18} columns, while 30% ACN buffered with 15mM of both NaH_2PO_4 and $NaCH_3COO$ at similar pH for Alltech Altima C_{18} column.

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Table 1. pH effect on the separation the acidic sample on Alltech Altima C_{18} column.

	Name of acids	Retention Time (min)			
		pH 2.90	pH 3.50	pH 4.02	pH 4.52
1	4-Hydroxybenzoic Acid	4.82	4.82	4.77	4.66
2	Acetylsalicylic Acid	8.76	8.53	7.63	6.12
3	Benzoic Acid	10.22	10.17	9.74	8.79
4	4-Methoxyphenyl Acetic Acid	10.78	10.63	10.55	6.12
5	3,5-Dinitrobenzoic Acid	14.53	10.63	7.31	10.00
6	o-Toluic Acid	15.91	15.82	14.96	13.15
7	Phenylpropanoic Acid	16.72	16.69	16.68	15.96

Table 2. Comparison of simulated DryLab© with experimental results at pH 3.01 on Alltech Altima C_{18} Column.

	Name of acids	Retention Time (min)		
		Simulated	Experimental	% Agreement
1	4-Hydroxybenzoic Acid	4.82	4.75	98.5
2	Acetylsalicylic Acid	8.76	8.74	99.8
3	Benzoic Acid	10.22	10.18	99.6
4	4-Methoxyphenyl Acetic Acid	10.82	10.77	99.5
5	3,5-Dinitrobenzoic Acid	14.60	13.28	91.0
6	o-Toluic Acid	15.91	15.93	100.1
7	Phenylpropanoic Acid	16.72	16.79	100.4

Figure 1. Separation of the mixture of weak acids on three different column types using a mobile phase of 30% ACN buffered with 15mM of both $NaCH_3COO$ and NaH_2PO_4 at pH 3.01: (a) 25 cm Alltech Altima C_{18}Column, (b) 25 cm Burdick & Jackson C_{18} Column, (c) 15 cm Alltech Nucleosil C_{18} Column.

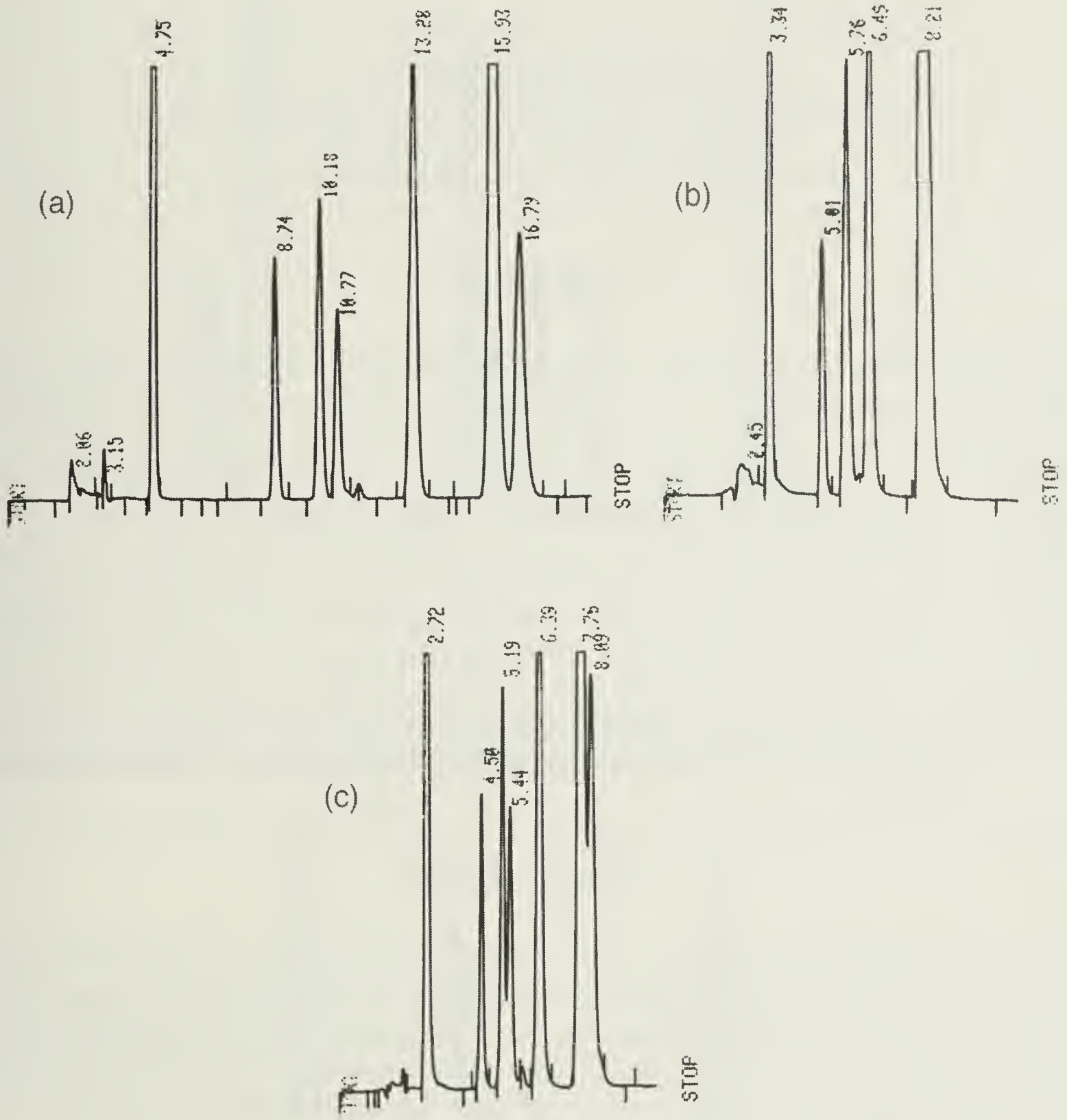


Figure 2. Separation of the mixture of weak acid on 25 cm Burdick & Jackson C_{18} Column using a mobile phase of 20% ACN buffered with 70mM $NaCH_3COO$ and 15mM NaH_2PO_4 at pH 3.01.

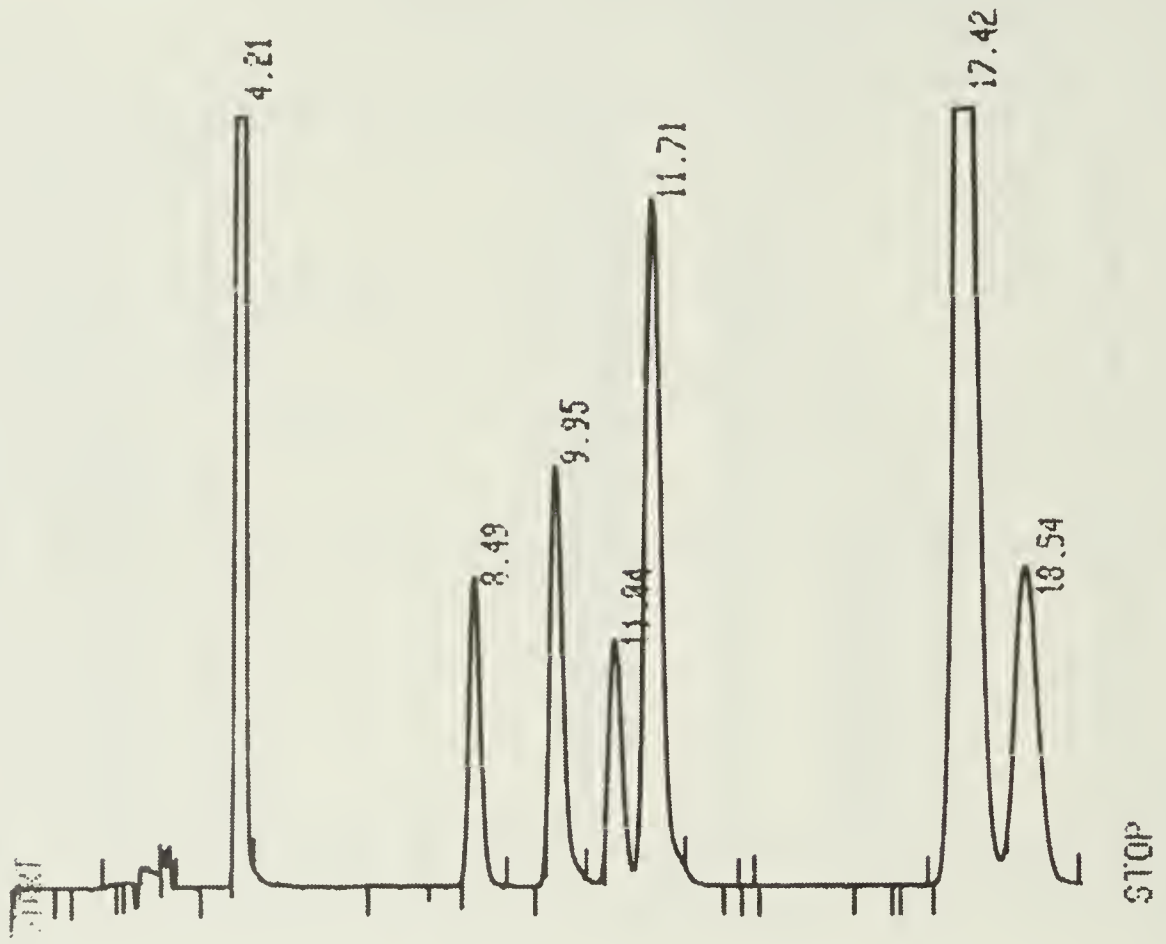
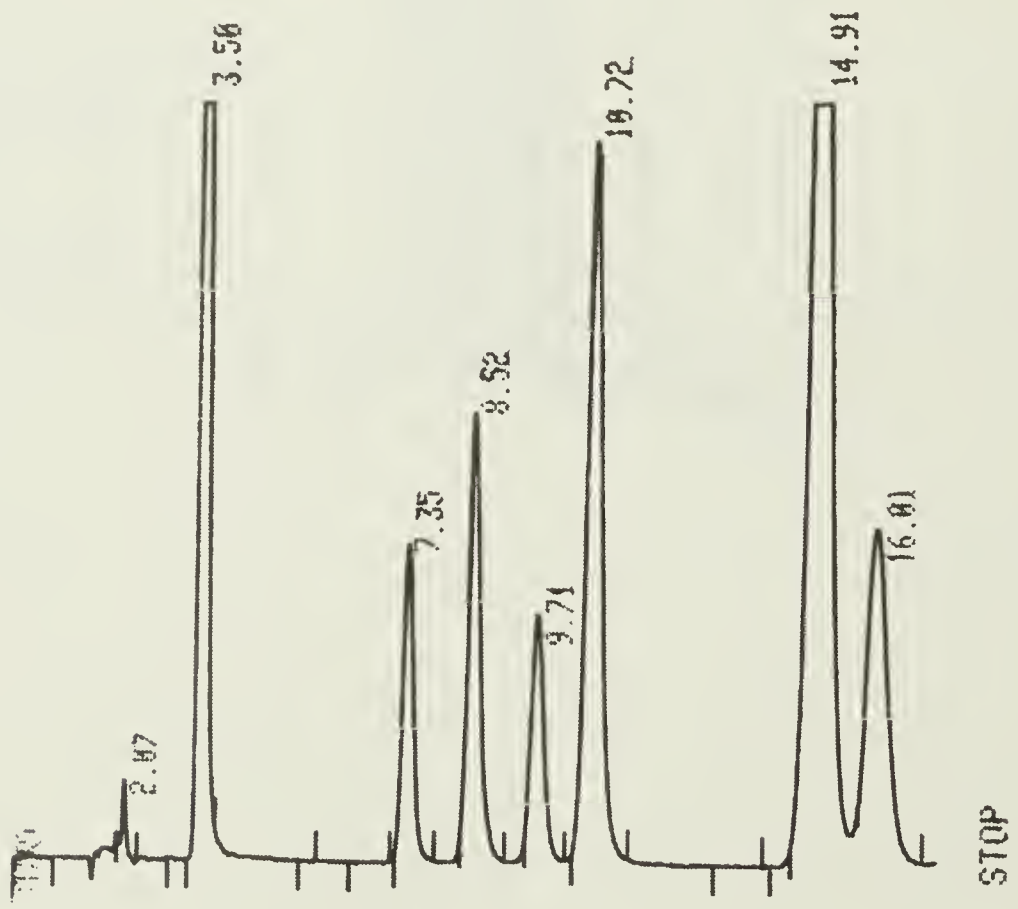


Figure 3. Separation of the mixture of weak acids on 15 cm Alltech Nucleosil C_{18} Column using a mobile phase of 20% ACN buffered with 70mM $NaCH_3COO$ and 15mM of NaH_2PO_4 at pH 3.01.



Transactions of the Illinois State Academy of Science
(2005), Volume 98, #3&4, pp. 145-157

received 1/25/05
accepted 9/18/05

Rugose Corals of the Livingston Limestone Member, Bond Formation, Coles and Edgar County, Illinois

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ABSTRACT

The rugosan coral species *Lophophyllidium proliferum* (McChesney, 1860) has long been associated with the Pennsylvanian (Missourian) strata of the Illinois Basin. The neotype established by Jeffords (1942) and associated specimens collected near Springfield, IL are nearly identical to the study samples from the Livingston Limestone member exposure at the Charleston Stone Company quarry in Coles County, IL and a similar site behind St. Aloysius Church in Edgar County, IL. Previous studies described *L. proliferum* as the only identified coral species in the local exposures. New data verify the existence of two additional rugosan species: *Lophamplexus westii* (Beede, 1898) and *Geyerophyllum* sp. cf. *G. broilii* Heritsch, 1936. The presence of these additional species indicates a more diverse faunal community than previously described and verifies the faunal correlation between the Bond Formation of Illinois and the Zone 4 Missourian Rocks of Kansas as expressed by Cocke (1974).

INTRODUCTION

The genotype for *Lophophyllidium* Grabau, 1928: *Cyathaxonia prolifera* McChesney, 1860, neotype: *Lophophyllidium proliferum* (McChesney, 1860), was first described in Pennsylvanian shale near Springfield, IL in the northwest section of the Illinois Basin. Jeffords (1942, p. 214) borrowed nine specimens from the Worthen collection at the Illinois Geological Survey to establish the neotype, as there is no record of the original specimens used by McChesney. The Worthen specimens were collected from beds above the No. 8 coal, now known as the Chapel Coal (ISGS, 2005, fig. 2), near Springfield, placing them in the Patoka Formation (Lower Missourian), below the Bond Formation stratigraphically (Jacobson, 2004) (Figure 1).

The Livingston Limestone Member of the Bond formation (Mid-Missourian) has also yielded specimens of *L. proliferum* (McChesney). Gilliam (1973) and Stratton (1991) reported the presence of this species locally at the Charleston Stone Company quarry; no other species had been described from this site. In contrast, studies of similar faunal zones in Iowa, Nebraska and Kansas have yielded multiple genera including: *Lophamplexus*, *Stereostylus* (Jeffords, 1947), *Caninia* and *Geyerophyllum* (Cocke, 1970).

STRATIGRAPHY

The type section for the Livingston Limestone member is located in Clark County, IL along exposures near Big Creek, SE1/4, NW1/4, sec. 6, T. 11 N., R. 11 W, consisting of an upper limestone, 1.5 to 2.5 m of shale, which locally includes a thin coal bed, and a lower limestone (Giffin, 1978, p. 3-4). The Livingston Limestone is now recognized as correlative to the Millersville Limestone (Stratton, 1991, p. 48) and the La Salle Limestone (Jacobson, 1983), members of the Bond Formation (Jacobson, 2004); original reference by A. H. Worthen (1895), Illinois Geological Survey, v. 6, p. 11-19 (Keroher, 1966). The Charleston Stone Company quarry is located in Coles County, IL at NE1/4, SW1/4, NW1/4, sec. 5, T. 12 N, R. 10 E (Stratton, 1991, p. 48), and St. Aloysius Church is located in Edgar County about 5 miles northeast of Paris, IL, SW1/4, SE1/4, NE1/4, sec. 10, T. 14 N, R. 11 W (Giffin, 1978, p. 166). Strata exposed at the two study sites are on opposite flanks of the LaSalle Anticlinorium (Weller, 1906), which trends southward through the heart of the Illinois Basin (Stratton, 1991, p. 48). The Charleston quarry is located on the western slope of the uplift and St. Aloysius Church sits on the eastern slope.

Coles County, IL. The Charleston Stone Company quarry exposure consists of upper and lower limestone benches separated by a narrow layer of shale (Figure 2). The upper limestone section is fine grained, light-gray in color, massive and contains large crinoid columns and brachiopods. The lower limestone section is medium light gray in color, very fine grained, dense and massive (Stratton, 1991, fig. 28) and is the primary quarried material. Both benches are classified as Algal Bank limestones (Fraser, 1991). The shale separating the two limestone sections is greenish in color, calcareous and the main source of fossils from the quarry, which Stratton (1991, p. 50-51) described as yielding the most diverse, abundant and best preserved marine faunas in the Illinois Basin; however, fossiliferous areas seem to be localized. While old quarry pits on the east side of the Embarrass River contained highly fossiliferous bed sets, newly exposed sections five hundred meters away lack macro fossils and seem anoxic.

Edgar County, IL. The St. Aloysius exposure of the Livingston Limestone Member is correlative to the Charleston site (Giffin, 1978, fig. 8). At the waterfall behind the church, the upper limestone bench has been eroded down to about a foot in thickness and overhangs the underlying shale. The shale unit at this site is crumbly and unconsolidated with numerous finely detailed corals and brachiopods. Specimens of *Lophamplexus westii* (Beede, 1898) are more common in the St. Aloysius exposure than in the Charleston quarry and are generally more intact.

METHODS

Field observation and collection. Sample material for the study came from three sources: the spoil piles at the Charleston Stone Company quarry, a stream cut exposure behind St. Aloysius Church in Edgar County and the Livingston Collection at Eastern Illinois University. The bulk of the sampling is from the quarry; however, some of the more diverse specimens were gathered from the St. Aloysius exposure. Over 150 samples were obtained with several representative specimens from each of the three morphologically dissimilar groups chosen for thin sectioning.

Material examined. Ninety-three specimens of *L. proliferum* (McChesney) were recovered; all but seven coming from the spoil piles at the Charleston quarry site. Many of the samples are extremely small, immature and complete at the apex. Nine reasonably intact mature corallites were selected for thin sectioning. Nine transverse and five longitudinal sections were prepared from the samples.

Fifty-five specimens of *L. westii* (Beede), many consisting of broken middle segments, were recovered (twenty of these collected at the St. Aloysius site) with eleven specimens from the lot selected. In all, ten transverse and nine longitudinal sections were prepared.

Seven specimens of *Geyerophyllum* sp. cf. *G. broilii* Heritsch were acquired for the study. Two previously unidentified and relatively intact corallites came from the EIU Livingston collection. The other five samples are partial corallites recovered from the Charleston quarry spoil piles. Five transverse and four longitudinal sections were prepared with specimens 075, 084 and 101 photographed and preserved intact for future study.

Two recently collected and unidentified specimens demonstrate extreme flaring and complete calices. A third intact specimen located in the EIU collection and labeled *Geyerophyllum rude* is complete with holdfasts in a limestone matrix. All three specimens were preserved intact.

SYSTEMATIC PALEONTOLOGY

Systematics used in agreement with the *Treatise on Invertebrate Paleontology Part F* (Hill, 1981a, 1981b). All study specimens are reposited in the Livingston Collection at Eastern Illinois University, Charleston.

***Lophophyllidium proliferum* (McChesney, 1860)**

Type species. There is no record of the holotype used by McChesney in his original description (Jeffords, 1942, p. 214). The neotype was established by Jeffords (1942) and is reposited in the Illinois State Geological Survey Collections, Urbana as W46064 (?or 4064a), but is probably lost (Hill, 1981a, p. F335). Syntype KUM 52878, as chosen by Jeffords (1942) is reposited at the University of Kansas Museum (Fedorowski, 1974, pl. 60, fig. 1).

Diagnosis. Corallite conical, except in gerontic sections, having a strong oval or plate-like columella with median lamella, formed as an extension of the counter septum, extending the entire length of the corallite and sometimes projecting distally. A reduced cardinal septum lies in a conspicuously shaped fossula, with 20 to 22 rhopaloid major septa in a bilateral arrangement common to lophophyllid corals and illustrated by Jeffords (1942, pl. 1, figs. 1-3) (Figure 3.1). In longitudinal sections, thin tabulae slope upwards from a moderately thick theca to a strong axial structure (Figure 3.2).

External description. Corallites generally maintain a conical shape that gently curves in the plane of the counter-cardinal septa (Figure 3.3). The epitheca is marked by distinct longitudinal interseptal ridges and transverse growth wrinkles. Rejuvenation is not evi-

dent in any of the samples; however, one specimen did demonstrate evidence of regeneration after damage.

In a certain number of study specimens the columella distally projects several millimeters above the floor of the calice. Only on the uppermost edge of the calice does *L. proliferum* enter a somewhat breviseptal stage. Intact specimens sometimes reveal a deep calice with shortened septa and a solitary or reduced columella. The damage sustained during burial provides an incomplete picture of the mature upper corallite.

Occurrence. The holotype and neotypes were collected from the beds over Coal No. 8, Trivoli cyclthem (sic), Missouri series near Springfield, IL (Jeffords, 1942, p. 214, 219). This roughly correlates to the Lower Missourian faunal zones of the Patoka Formation (Jacobson, 2004). The Livingston samples are from the younger Upper Bond Formation of the Middle Missourian Series (Figure 1). Shimer and Shrock (1944, p. 87) described *L. proliferum* as widespread and common in Pennsylvanian rocks from the Mississippi Valley to Texas and New Mexico.

Discussion. The distinguishing feature of this species is the strong, laterally compressed and vertically striated axial column (Grabau, 1922, p. 47) extending the length of the corallite. The neotype of the species is 30.0 mm in length and 12.7 mm in diameter at the calice. Eight other specimens in the same lot ranged from 12.1 to 33.3 mm in length and 8.2 to 10.4 mm in diameter (Jeffords, 1942, p. 215). These values agree well with the Livingston test samples, having a range from 15 to 48 mm in length and 8 to 10 mm in diameter (Table 1), with some of the wider specimens having been laterally compressed. The large number of *L. proliferum* samples in the study contained one unique specimen (032) that accounted for the increased range. Some immature quarry specimens had diameters of 5 to 6 mm and lengths between 10 and 12 mm.

Jeffords (1942) described the calice as moderately deep with the laterally compressed columella projecting into the lower part. In several weathered specimens, the columella extended a few millimeters above the rest of the corallite (p. 215).

***Lophamplexus westii* (Beede, 1898)**

Type species. The University of Kansas Museum houses the type material studied by Beede. The holotype is No. 811021a from the "Upper Coal Measures" of the Hertha Limestone of Kansas City (Jeffords, 1947, p. 72).

Diagnosis. Corallites appear conico-cylindrical with rejuvenation occurring early and often in mature individuals. Specimens display an overall cylindrical shape and inconsistent curvature, with surface features similar to *L. proliferum*. Points of rejuvenation are usually marked by a change in the direction of growth. Thin attenuate septa are generally short, although they lengthen and join together in rejuvenation structures (Figure 3.4). The axial column is thin and discontinuous after early growth, only to reappear during rejuvenation and at the base of the calice in mature specimens. Some individuals have a column that extends for prolonged distances. Tabulae are complete, flat-topped and intersected by the axial column when present (Figure 3.5). Most specimens display some amplexoid tendencies.

External description. Corallites are narrow and cylindrical in mature regions, conical and similar to *L. proliferum* in early stages. Onset of cylindrical shape is sometimes accompanied by the first rejuvenation. Mature specimens show either extreme curvature or variations in growth direction, especially during rejuvenation. Areas of rejuvenation are highlighted by thick transverse growth wrinkles followed by a narrowing of the corallite. The epitheca is marked by distinct longitudinal interseptal ridges similar to *L. proliferum* (Figure 3.6).

The similarities in external morphology between *L. westii* and *L. proliferum* are enough to require thin sectioning for positive identification in some cases. A general field diagnosis can be made for *L. westii* if the corallite demonstrates rejuvenated sections corresponding with deeply incised transverse growth wrinkles, changes in growth direction for rejuvenated sections and an overall cylindrical shape. *L. westii* samples have a greater variability in growth curvature when compared to *L. proliferum*, which generally maintains a gently curved and conical shape; in addition, *L. westii* corallite diameters are generally 1-2 mm less than *L. proliferum* (Table 1).

Occurrence. The type materials are from the Hertha Limestone of the Bronson Group, Missourian Series (Pennsylvanian), at Kansas City, Missouri (Jeffords, 1947, p. 72), placing them in Zone 1 of the Missourian Limestones of Kansas (Cocke, 1970, table 1). Additional specimens have been recognized from the Bethany Falls Limestone in Bourbon County, Kansas and from a Bronson Group exposure in Neosho County, Kansas (Jeffords, 1947, p. 72). In an earlier study, Jeffords (1942, table, p. 253) reported the occurrence of (syn) *Lophophyllum westi* (sic) Beede in the Missourian rocks of Kansas.

Discussion. The figured specimens illustrated by Jeffords (1947, pl. 24) demonstrate the inherent variability in the septal layouts during various stages of *L. westii*. Repeated periods of rejuvenation are described in which adolescent characters reappear immediately above a breviseptal stage (Jeffords, 1947, p. 70). *L. westii* differs structurally from other *Lophamplexus* Moore and Jeffords species with its long, crooked cylindrical shape and frequent rejuvenations (Jeffords, 1947, pls. 25.4-25.5). The axial structure reappears just before rejuvenation and disappears during sporadic amplexoid growth stages. A persistent columella separates this species from *L. vagus*, *L. spanius*, *L. phractus*, and *L. brevifolis* (Jeffords, 1947, pls. 22-24, 27, 28); however, internal morphology revealed during the sectioning of the study samples contained a range of structural variation suggesting that either multiple *Lophamplexus* species are present in the quarry, or *L. westii* corallites are inherently variable as to indicate subjunctive synonymy. Longitudinal sections reveal the breviseptal morphology that is characteristic of the genus and constitutes a major ontological and phylogenetic difference between *L. westii* and *L. proliferum*. Although *L. proliferum* septa shorten in gerontic stages, the columella is strong and persistent; unlike the weak, sporadic nature of the columella in *L. westii* (Table 2).

***Geyerophyllum* sp. cf. *G. broilii* Heritsch, 1936**

Type species. ?*Geyerophyllum broilii* Heritsch, 1936, was first described in the Pennsylvanian (Missourian) rocks of Kansas (Hill, 1981b, p. F406).

Diagnosis. This species generally contains corallites with gently flaring shapes; however, the study samples flare strongly, similar to some of the Cocke (1970) study samples (pl.

8, figs. 2, 8). The epitheca is marked by longitudinal ridges and variable transverse growth wrinkles (Figures 4.1, 4.4). Septal layout is similar to lophophyllid corals in nepionic stages (Cocke and Cocke, 1969, p. 942). Mature sections are distinguished by long thin septa and a narrow dissepimentarium with moderate lonsdaleoid characteristics (Figure 4.2). Septa are attenuate and somewhat crooked. Minor septa are reduced in the tabularium; while major septa project axially, almost to the column when present. The axial structure is strong and oval in ephebic sections, has a spinose or denticulate appearance and is connected to the cardinal septum. Dissepiments are elongated, irregular in size and bounded by an inner wall that separates the dissepimentarium from the tabularium (Figure 4.3). Tabulae are rare to absent in mature sections.

External description. Corallites strongly flare in ephebic stages. Longitudinal interseptal ridges and transverse growth wrinkles are similar to *L. proliferum*; however, the strongly flaring shape is in sharp contrast to both *L. proliferum* and *L. westii*. The calice of mature corallites is sometimes found preserved without the lower sections.

Occurrence. Cocke (1970) described *Geyerophyllum* sp. cf. *G. broilii* as occurring in the Wyandotte and Plattsburg Formations of the Zone 4 Missourian limestones of Kansas. Specimens from the Argentine Limestone of the Wyandotte Formation possess gently flaring shapes, a stellate columella and lanceolate major septa (p. 49).

Discussion. Cocke (1970, p. 46) described *Geyerophyllum* sp. cf. *G. broilii* as differing from other *Geyerophyllum* corals by having a moderately flaring shape and lacking a prominent lonsdaleoid dissepimentarium. Some lonsdaleoid characteristics are present in the quarry sections, especially above the axial column; no sections displayed prominent lonsdaleoid features as in *G. patulum* Cocke (1970, pl. 7, figs. 6a, 7a). A highly denticulate axial column is indicated for *Geyerophyllum* sp. cf. *G. broilii* (Cocke, 1970, p. 8, figs. 4-5). Cocke (1970) noted that when specimens are in an algal-rich calcilutite, they tend to have flaring shapes, a strongly denticulate columella and rather well developed lonsdaleoid dissepiments (p. 42). The Charleston study samples demonstrate all three characteristics (Table 2).

Geyerophyllum sp. cf. *G. broilii* differs from *G. rude* in having a strongly oval and denticulate axial column; however, if it can be demonstrated that the axial column varies due to environmental conditions, then the two may be conspecific.

Geyerophyllum specimens are rare in the Livingston Limestone Member. Only seven partial corallites were collected out of over 150 total rugosan samples. No dissepimental corals have presently been recovered from the St. Aloysius exposure; although one sample in the Eastern Illinois University Livingston Collection is labeled as having been recovered from the site in 1971. Cocke (1974) later commented that the Livingston Limestone in Illinois has corals that are similar to those of Zone 4 of the Missourian rocks of Kansas. *Geyerophyllum* sp. cf. *G. broilii* is one of three *Geyerophyllum* genera identified in Zone 4 (Cocke, 1970, table 1).

SUMMARY

Agreement between the structural morphology of the study specimens and historic descriptions of Paleozoic corals by Jeffords (1942, 1947), Moore and Jeffords (1945), Cocke (1970), Hill (1981a,b) and Fedorowski (1974, 1987) demonstrates that multiple phylogenetic lineages exist in the rugosan corals of the Livingston Limestone member, revealing a more diverse fauna than earlier described. The lack of specific studies on previously collected Charleston Stone Company quarry and St. Aloysius samples have led previous researchers to label most collected specimens as either *Lophophyllidium* sp. or *Lophophyllidium proliferum*. Clearly, three distinct genetic lines: *Lophophyllidium* Grabau, *Lophamplexus* Moore and Jeffords and *Geyerophyllum* Heritsch flourished in the warm, near offshore epeiric sea that covered central Illinois during the Mid-Missourian (Gilliam, 1973, p. 32).

ACKNOWLEDGMENTS

Gratitude is extended to Dr. Craig Chesner of EIU for supplying the necessary materials required in the serial grinding of the study specimens. Further thanks are extended to the Booth Library at Eastern Illinois University for acquiring numerous obscure periodicals, some dating back to the nineteenth century.

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Figure 1. Relative Illinois Pennsylvanian stratigraphy with formations and common members adapted and modified from Willman et. al, 1975 (Jacobson, 2004).

SYS.	Series	Formation	Member
PENNSYLVANIAN	Virgilian	Mattoon	
			Greenup Ls.
			Omega Ls.
	Missourian	Bond	Livingston Ls.
			Carthage Ls.
		Patoka	
			Chapel Coal
			Trivoli Ss.
	DesMoinesian	Shelburn	
			Danville Coal
		Carbondale	Herrin Coal
			Springfield Coal
			Francis Creek Sh.
			Colchester Coal
		Tradewater	Carrier Mills Sh.
	Atokan		Grindstaff Ss.
	Morrowan	Caseyville	Pound Ss.
			Battery Rock Ss.

Figure 2. Charleston Stone Company quarry stratigraphic column (adapted from Giffin, 1978, p. 38).

Figure 3. Images of study samples. Scale is in centimeters. (1.) Specimen 027, *L. proliferum*, transverse section, note median lamella. (2.) 011, *L. proliferum*, longitudinal section, note strong axial structure. (3.) 027, *L. proliferum*, external view, projecting columella broken off. (4.) 077, *L. westii,* transverse section, one of several septal variations. (5.) 077, *L. westii*, longitudinal section, note breviseptal region and tabulae morphology. (6.) 077, *L. westii*, external view.

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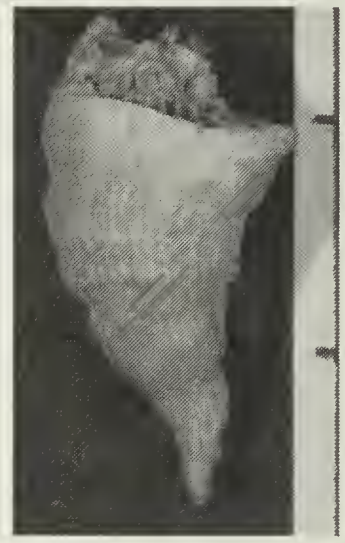

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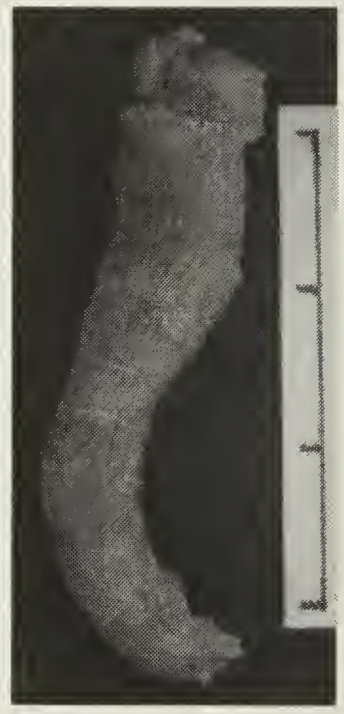

Table 1. Summary table of corallite dimensions. All measurements are in millimeters. N/A listing is due to lack of data either from damage during preparation or initial condition of the specimen prevented further testing.

Specimen	CD	Length	NS	ID	Locale	Notes
001*	10	20	24	*L. proliferum*	CSQ	
011	9	19	24	*L. proliferum*	CSQ	
021	7	15	n/a	*L. proliferum*	CSQ	extended column
022	10	18	25?	*L. proliferum*	CSQ	compressed calice
027	10	21	24	*L. proliferum*	CSQ	complete apex
032	10	48	24	*L. proliferum*	CSQ	upper LS
071	10	20	24	*L. proliferum*	CSQ	
082	9	15	24	*L. proliferum*	CSQ	
Average	9	22				
Range	7-10	15-48				
006	7	30	n/a	*L. westii*	CSQ	compressed calice
018	6	20	n/a	*L. westii*	CSQ	mid section
029	9	15	20	*L. westii*	CSQ	complete apex
034	7	20	20	*L. westii*	CSQ	conical shape
043	6	17	16	*L. westii*	CSQ	
076	7	22	20	*L. westii*	St. A	highly curved
077	8	42	19-22	*L. westii*	St. A	partial
080	10	n/a	23	*L. westii*	CSQ	upper calice only
094	8	37	22	*L. westii*	St. A	partial
096	9	41	24	*L. westii*	St. A	partial
Average	8	27				
Range	6-10	15-42				
068	13	14	n/a	sp. cf. *G. broilii*	CSQ	partial
069	16	n/a	23	sp. cf. *G. broilii*	CSQ	upper calice only
072	14	12	23	sp. cf. *G. broilii*	CSQ	partial
075	24	10	49?	sp. cf. *G. broilii?*	CSQ	highly flared
084	19	n/a	n/a	sp. cf. *G. broilii*	CSQ	upper calice only
100	20	13	n/a	sp. cf. *G. broilii*	CSQ	mostly complete
101	20	12	47?	sp. cf. *G. broilii?*	CSQ	nicely polished
Average	12	18				
Range	13-24	10-14**				

*Specimens reposited under the catalog number EIU/LC 121613

**poor data due to incomplete specimens

CD: corallite diameter NS: number of major septa

Table 2. Summary of major corallite characteristics.

TABLE OF CORALLITE CHARACTERISTICS			
Character	*L. proliferum*	*L. westii*	sp. cf. *G. broilii*
Shape	conical, gently curved	conico-cylindrical, straight to bent	flaring, upright
Axial Column	solid, oval, projecting	weak, thin, sporadic	strong, oval, spinose, shortened distally
Major Septa	strong, rhopaloid	weak, shortened, highly variable	thin, crooked, attenuate
Minor Septa	absent or greatly reduced	reduced	thin, crooked, reduced in tabularium
Tabulae	short, thin, sloping upward into column	complete, flat topped domes, flair w/ column	none above early ephebic stages
Dissepiments	none	none	narrow dissepimentarium moderate lonsdaleoid dissepiments
Rejuvenation	none	frequent	none

Figure 4. Images of study samples. Scale is in centimeters. (1.) Specimen 072, *Geyerophyllum* sp. cf. *G. broilii*, external view. (2.) 072, sp. cf. *G. broilii*, longitudinal section. (3.) 072, sp. cf. *G. broilii*, transverse section, note sporadic lonsdaleoid dissepiments. (4.) Specimen 100, sp. cf. *G. broilii*, highly flaring specimen. (5.) 100, sp. cf. *G. broilii*, oblique longitudinal section.

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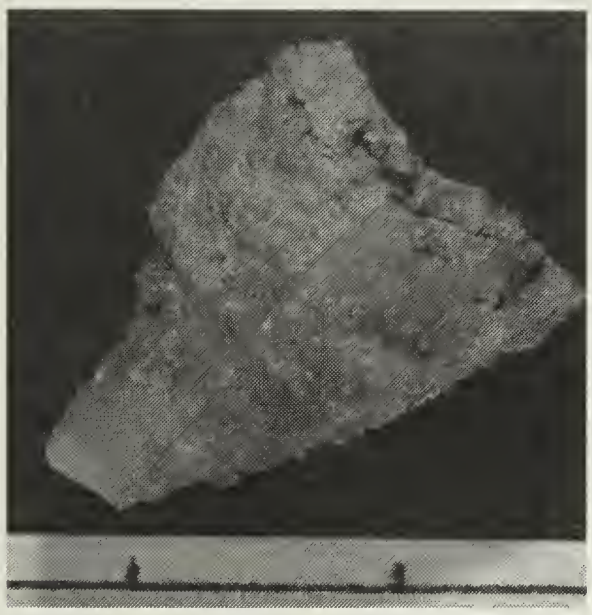

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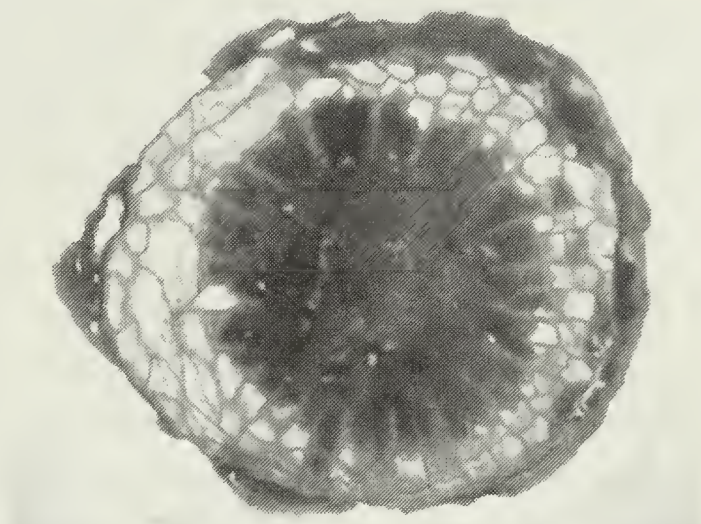

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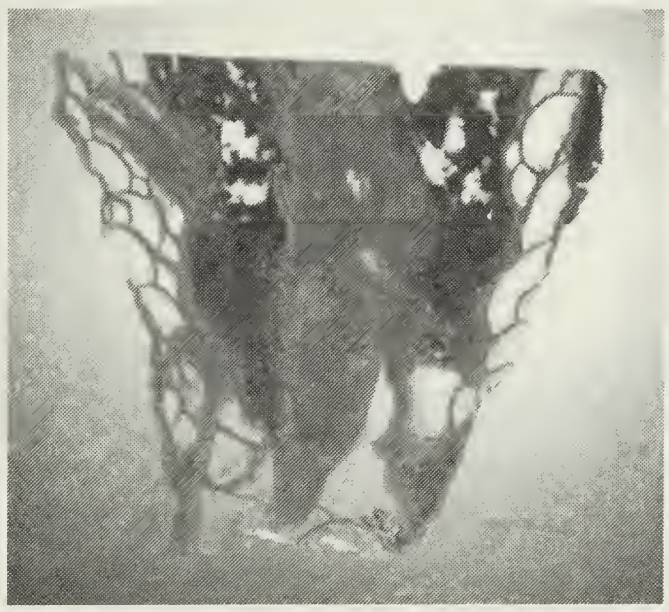

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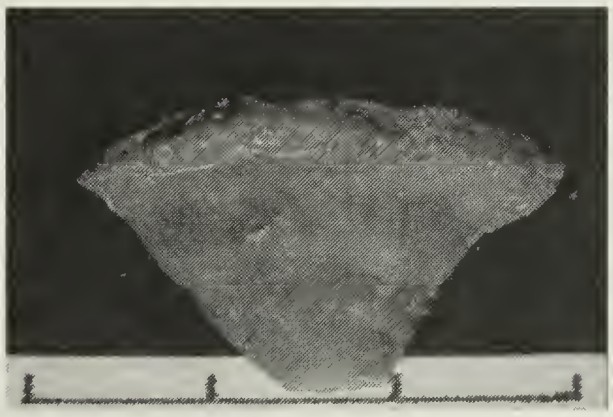

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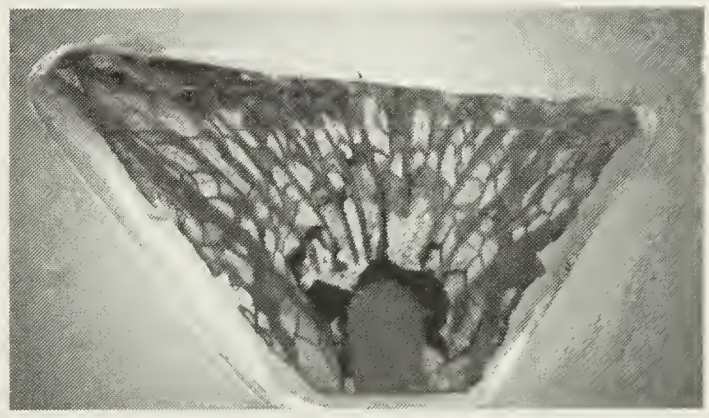

Transactions of the Illinois State Academy of Science
(2005), Volume 98, #3&4, pp. 159-169

received 5/31/05
accepted 10/30/05

Freshwater Mussel (Bivalvia: Unionidae) Survey of Kyte River, Ogle County, Illinois

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ABSTRACT

The freshwater mussel fauna of Kyte River, Ogle County, Illinois, was investigated during a 2004 survey. Live individuals of 15 species, including one individual of the state-threatened black sandshell *Ligumia recta*, were collected during 32 person-hours of sampling at eight mainstem stations; three additional species, including the state-threatened slippershell mussel *Alasmidonta viridis*, also were found but only as valves. Five stations supported sufficient species richness and abundance and qualify for the Illinois Natural Areas Inventory.

Key Words: Mollusca, unionids, bivalve, Rock River

INTRODUCTION

Freshwater mussels are important components of stream ecosystems (Strayer and Smith, 2003). Due to their sensitivity to stream flow and substrate, filter feeding habits, and relative inability to move far in response to environmental stresses, freshwater mussels act as biological indicators of stream condition and integrity. They have undergone a drastic decline during the past century and have become one of the most imperiled groups of animals in North America (Williams et al., 1993). More than two-thirds of the approximately 300 historical species in North America are extinct, federally-listed as endangered or threatened, or in need of conservation status.

This study was undertaken to determine the current freshwater mussel fauna of Kyte River. The objectives were to obtain information concerning status of the fauna and to collect data that can serve as a basis for comparison with other stream basins in Illinois. Prior to this survey, no comprehensive freshwater mussel survey of Kyte River had been conducted, and both historical and current data on the fauna were limited. Only five species (cylindrical papershell *Anodontoides ferussacianus*, plain pocketbook *Lampsilis cardium*, fatmucket *Lampsilis siliquoidea*, pink papershell *Potamilus ohiensis*, and pimpleback *Quadrula pustulosa*) from the Kyte River basin have been recorded in museum and literature records (Illinois Natural History Survey [INHS] Mollusk Collection data).

Kyte River is about 32 mi long and drains an area of nearly 200 mi^2. It is in the Rock River Hill Country and the Grand Prairie natural divisions of DeKalb, Lee, and Ogle counties (Schwegman, 1973). The river originates near Kings in Ogle County and flows south through Rochelle, bending near the Ogle-Lee county line to flow west-northwest before reaching its confluence with the Rock River south of Oregon in Ogle County (Fig. 1).

METHODS AND MATERIALS

Freshwater mussel data were collected at eight mainstem stations (Fig. 1; Appendix 1) in Kyte River from 21-22 September 2004. Live freshwater mussels and valves of dead specimens were collected by hand during for four person-hours at each station. Shell material was classified as live, dead (valves with tissue present or shiny nacre and intact periostracum), or relict (valves with chalky nacre and worn periostracum) based on condition of best specimen found. Efforts covered all substrate types at each station. All specimens were identified to species using Cummings and Mayer (1992), and common and scientific names follow Turgeon et al. (1998) except for the recognition of subspecies. Voucher specimens (usually valves) of each species from each station were retained and deposited in the INHS Mollusk Collection, Champaign. For each species, the following data were recorded: 1) number of live individuals or condition of best shell found, and 2) evidence of juveniles, where juveniles were live individuals with three or fewer external growth rings. All non-vouchered live individuals were returned to the stream reach where they were collected.

Regression analysis was used to test whether extant species richness, historic species richness, and abundance increased from upstream to downstream. A species was considered extant at a station if it was represented there by live specimens or dead (not relict) valves, and a species was considered historic at a station if it was collected there either as live, dead, or relict. A t-test was applied to determine if historic species richness was significantly different from extant species richness. Statistical analyses were preformed with SAS, Version 8 (SAS Institute Inc, Cary, North Carolina).

A Mussel Classification Index, or MCI, (Szafoni, 2002) was calculated for each station. Freshwater mussel resources at each station were classified as Unique, Highly Valued, Moderate, Limited, or Restricted based on the following parameters: 1) extant species richness; 2) abundance estimates expressed as catch-per-unit-effort; 3) presence and number of intolerant species; and 4) recruitment proportion of live species represented by juveniles (Appendix 2).

RESULTS / DISCUSSION

Kyte River Freshwater Mussel Survey

A total of 681 live individuals of 15 species, including one individual of the state-threatened black sandshell *Ligumia recta* (IESPB, 2005), was collected in 32 person-hours in Kyte River; three additional species, including the state-threatened slippershell mussel *Alasmidonta viridis* (IESPB, 2005), also were found but only as valves (Table 1). These numbers are comparable to the 13 live species and 19 historic species found in the Green River basin (mainstem and tributaries), which is another Rock River tributary (Schanzle

and Kruse, 1994). The Rock River drainage historically had 44 species but only 30 have been collected alive since 1969 (Cummings and Mayer, 1997). Both extant and historic species richness from the Kyte River basin was conservative since tributaries were not sampled.

The most widespread species in Kyte River were plain pocketbook *Lampsilis cardium*, recorded as live at all eight stations sampled, and fragile papershell *Leptodea fragilis*, recorded as live at seven stations (Table 1). Other widespread species include elktoe *Alasmidonta marginata*, white heelsplitter *Lasmigona complanata*, giant floater *Pyganodon grandis*, creeper *Strophitus undulatus*, and pimpleback *Quadrula pustulosa*, all documented as extant at five stations (Table 1). This distribution suggests that most species in Kyte River are widely distributed and not confined to isolated populations. In the Green River mainstem, only *L. cardium* was collected alive at more than half of the nine stations (Schanzle and Kruse, 1994).

The number of extant species observed in Kyte River ranged from three to 12 per station, whereas the number of historic species varied from four to 14 (Table 1). These numbers exceeded those from the Green River mainstem, where zero to five extant species and one to six historic species were collected during four person-hours at each of nine stations (Schanzle and Kruse, 1994). Extant species richness and historic species richness did not significantly differ in Kyte River ($t = 0.01$, $P > 0.20$) suggesting that its freshwater mussel fauna still remains relatively intact. The difference in species richness between historic and extant ranged from zero to six per station. There was no statistical difference in either extant species richness ($r^2 = 0.48$, $P = 0.06$) or historic species richness ($r^2 = 0.18$, $P = 0.29$) from upstream to downstream in the 15 mi stretch of Kyte River sampled (Fig. 2a). This pattern might have been observed if more headwater stations were examined. An increase in species richness from upstream to downstream has been observed in the Rock River mainstem (Baker, 1926) and is typical of undisturbed, intermediate-sized rivers (Watters, 1992). Species richness in these types of streams typically increases as a function of enlarging drainage area, which usually offers decreased gradients, expanded habitat complexities, and higher fish diversity to serve as glochidia hosts (Vannote et al., 1980; Watters, 1992).

Abundance in Kyte River increased significantly ($r^2 = 0.63$, $P = 0.02$) from upstream to downstream (Fig. 2b). Abundance ranged from 14 to 202 live individuals per station (Table 1) and exceeded abundances in the Green River mainstem stations, which ranged from zero to 17 live individuals (Schanzle and Kruse, 1994). The most abundant species collected in Kyte River was *L. cardium* (66% of all live individuals); no other species made up more than 10% of live individuals collected (Table 1). *Lampsilis cardium* (60% of all live individuals), followed by *P. grandis* (12.5%) and *L. complanata* (10%), were the most abundant species collected in the Green River mainstem (Schanzle and Kruse, 1994). Notable in Kyte River was the abundance of *A. marginata* (8% of all live individuals), which prefers clean gravel substrates with good flow (Cummings and Mayer, 1992). This species was once considered a candidate for federal listing and although it is relatively uncommon, it is generally distributed in the northern half of Illinois (Cummings and Mayer, 1997). No live *A. marginata* was reported from the Green River basin (Schanzle and Kruse, 1994), but it has been found in the Rock River mainstem, the Pecatonica and Kishwaukee river basins, and Dry Creek (INHS Mollusk Collection data).

Two state-threatened species, live *L. recta* and relict shells of *A. viridis*, were collected in Kyte River (Table 1). *Ligumia recta* is found sporadically in northern Illinois where it is currently known from one-third of the drainages that historically supported it; the species is currently known from the Rock, Kankakee, and Galena/Apple river drainages as well as the Mississippi and Ohio rivers (Cummings & Mayer, 1997). Within the Rock River system, *L. recta* was not reported from the Green River basin (Schanzle and Kruse, 1994) but it has been recorded in the Rock River mainstem and the Pecatonica and Kishwaukee river basins (INHS Mollusk Collection data). *Alasmidonta viridis* was formerly widely distributed in the northern half of Illinois but is now sporadically found in a few Illinois River tributaries, including the Fox, Kankakee, Mackinaw, Sangamon, and Vermilion rivers as well as the Vermilion River of the Wabash River drainage (Cummings & Mayer, 1997). In the Rock River drainage, *A. viridis* was historically known from the Kishwaukee River basin and Kent Creek (INHS Mollusk Collection data) but not from the Green River basin (Schanzle and Kruse, 1994).

Recruitment was zero at one station but moderate to very high at the other seven (Table 2). Smaller (e.g., younger) individuals are difficult to locate and large samples are needed to accurately assess population demographics (Strayer and Smith, 2003). However, a small sample can provide evidence of recruitment if it includes individuals that are small or possess few external growth rings. Alternatively, a sample consisting of very large individuals with numerous external growth rings suggests a senescent population. Given the difficulties in assessing recruitment through detection of small individuals, these Kyte River data are biologically significant and suggest that the stream not only supports an abundant and diverse freshwater mussel fauna but also that populations of several species are reproducing.

Freshwater Mussel Fauna Classification

Based on MCI calculations, several sections of Kyte River support significant freshwater mussel resources and qualify for the Illinois Natural Areas Inventory (Table 2). One station ranked as Unique due to high species richness and abundance, intolerant species present, and evidence of recruitment for 90% of live species. Four stations ranked as Highly Valued due to high species richness and abundance and evidence of recruitment for at least 25% of live species. Two stations ranked Moderate due to low species richness and abundance, lack of intolerant species, and evidence of recent recruitment for <10% of live species. One station ranked Limited due to low species richness and abundance, lack of intolerant species, and no evidence of recent recruitment.

ACKNOWLEDGMENTS

The Vogls and the Worleys allowed access to their property. K. Anderson, D. Kirk, D. Ludwig, R. Olson, R. Schanzle, B. Semel, R. Vogl, and S. Vogl assisted in collecting. K. Cummings, G. Levin, D. Thomas, B. Tiemann, C. Warwick, and two reviewers offered constructive comments. The Illinois Department of Transportation provided partial funding.

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Table 1. Data from the 2004 freshwater mussel survey of Kyte River in Ogle County, Illinois (see Appendix 1 for station localites). D indicates those species collected as fresh-dead shell and R denotes those species collected as relict shell. Extant species are those that were represented by live or dead shell material. CPUE (catch-per-unit-effort) is number of live individuals per hour collected (all stations sampled for four person-hours). Recruitment is number live species with juvenile individuals per number of extant species. Illinois state-threatened species are marked with superscript ST.

Species	Common Name	Station No. 1	2	3	4	5	6	7	8	Mainstem Total	Relative Abundance
Subfamily Anodontinae											
Alasmidonta marginata	elktoe			10	21	12	10	R	1	54	7.93%
Alasmidonta viridis ST	slippershell mussel				R					0	0.00%
Anodontoides ferussacianus	cylindrical papershell	R			R		1	D	1	2	0.29%
Lasmigona complanata	white heelsplitter		6	21	8		4	2		41	6.02%
Lasmigona compressa	creek heelsplitter			R	R		1			1	0.15%
Pyganodon grandis	giant floater		7	3	R	2	1	1		14	2.06%
Strophitus undulatus	creeper	1	R		2	2	D	9	2	16	2.35%
Subfamily Ambleminae											
Amblema plicata	threeridge		R	R	R			R		0	0.00%
Fusconaia flava	Wabash pigtoe			1				6	2	9	1.32%
Quadrula pustulosa	pimpleback			1	1		1	23	16	42	6.17%
Subfamily Lampsilinae											
Actinonaias ligamentina	mucket			1				3	R	4	0.59%
Lampsilis cardium	plain pocketbook	40	1	24	42	15	35	118	174	449	65.93%
Lampsilis siliquoidea	fatmucket		R	2	3		3	3		11	1.62%
Leptodea fragilis	fragile papershell	1	D	3	3	1	2	18	5	33	4.85%
Ligumia recta ST	black sandshell							1		1	0.15%
Potamilus ohiensis	pink papershell		D					2	1	3	0.44%
Toxolasma parvus	lilliput						1			1	0.15%
Venustaconcha ellipsiformis	ellipse			R	R					0	0.00%
Number of individuals		42	14	66	80	32	59	186	202	681	
Number of extant species		3	5	9	7	5	11	12	8	15	
Number of historic species		4	8	12	13	5	11	14	9	18	
CPUE		10.5	3.5	16.5	20.0	8.0	14.8	46.5	50.5	21.3	
Recruitment		03/03	0/3	03/09	05/07	02/05	06/10	09/10	02/08		

Table 2. Mussel Classification Index (MCI) data from the 2004 freshwater mussel survey of Kyte River in Ogle County, Illinois (see Appendix 1 for station localities and Appendix 2 for calculating the MCI). Stations scoring Unique or Highly Valued or stations supporting 10+ extant species qualify for the Illinois Natural Areas Inventory.

Station	Number of extant species	Number of intolerant species	Catch-per-unit-effort	% species recruit	Species richness factor	Intolerant species factor	Abundance factor	Reproduction factor	MCI score	Resource Value
1	3	0	10.5	100%	2	1	3	5	11	Moderate
2	5	0	3.5	0%	3	1	2	1	7	Limited
3	9	0	16.5	33%	4	1	3	4	12	Highly Valued
4	7	0	20.0	71%	4	1	3	5	13	Highly Valued
5	5	0	8.0	40%	3	1	2	4	10	Moderate
6	11	0	14.8	60%	5	1	3	5	14	Highly Valued
7	12	1	46.5	90%	5	3	4	5	17	Unique
8	8	0	50.5	25%	4	1	4	3	12	Highly Valued

Figure 1. Station locations from the 2004 freshwater mussel survey of Kyte River in Ogle County, Illinois.

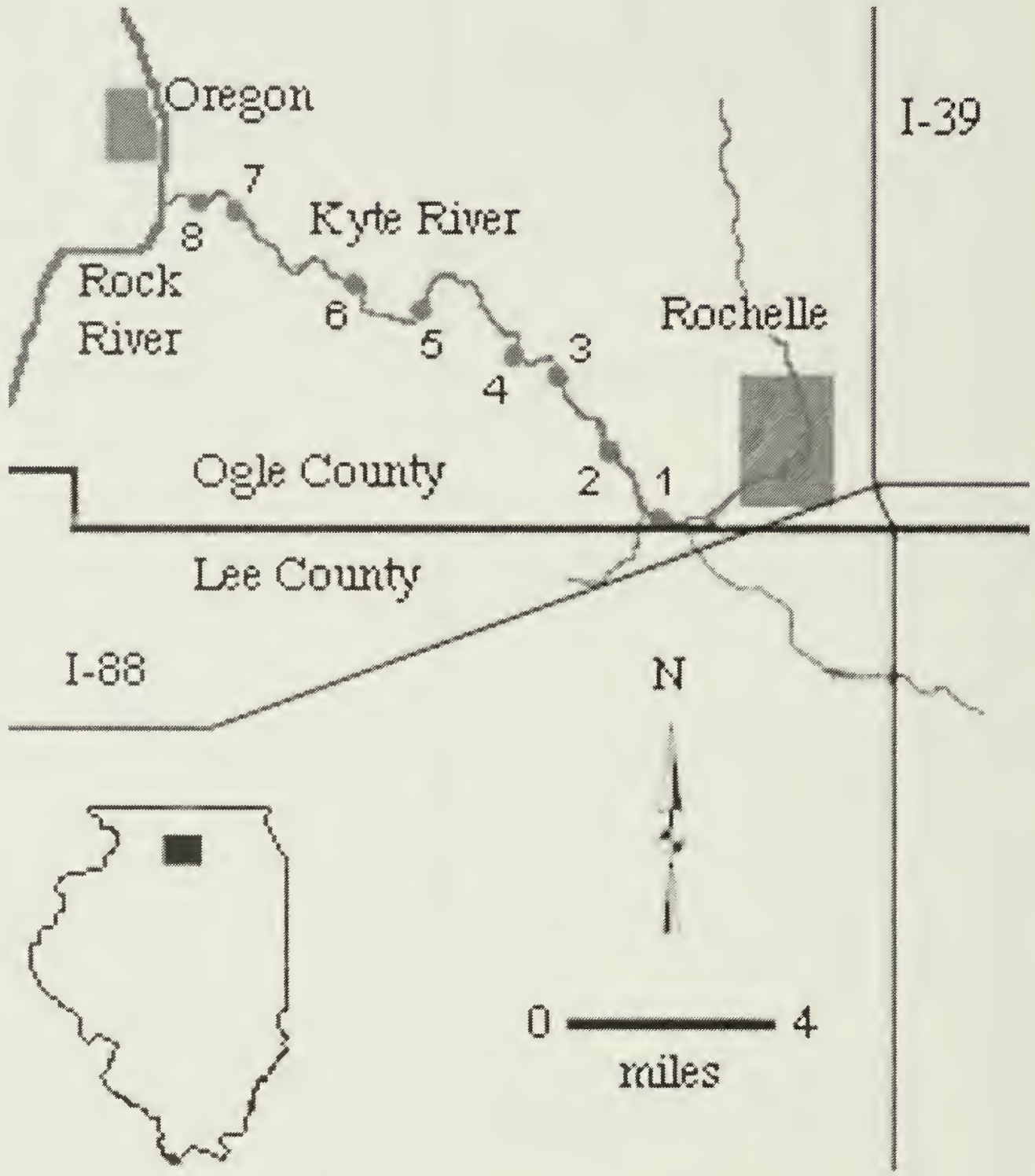
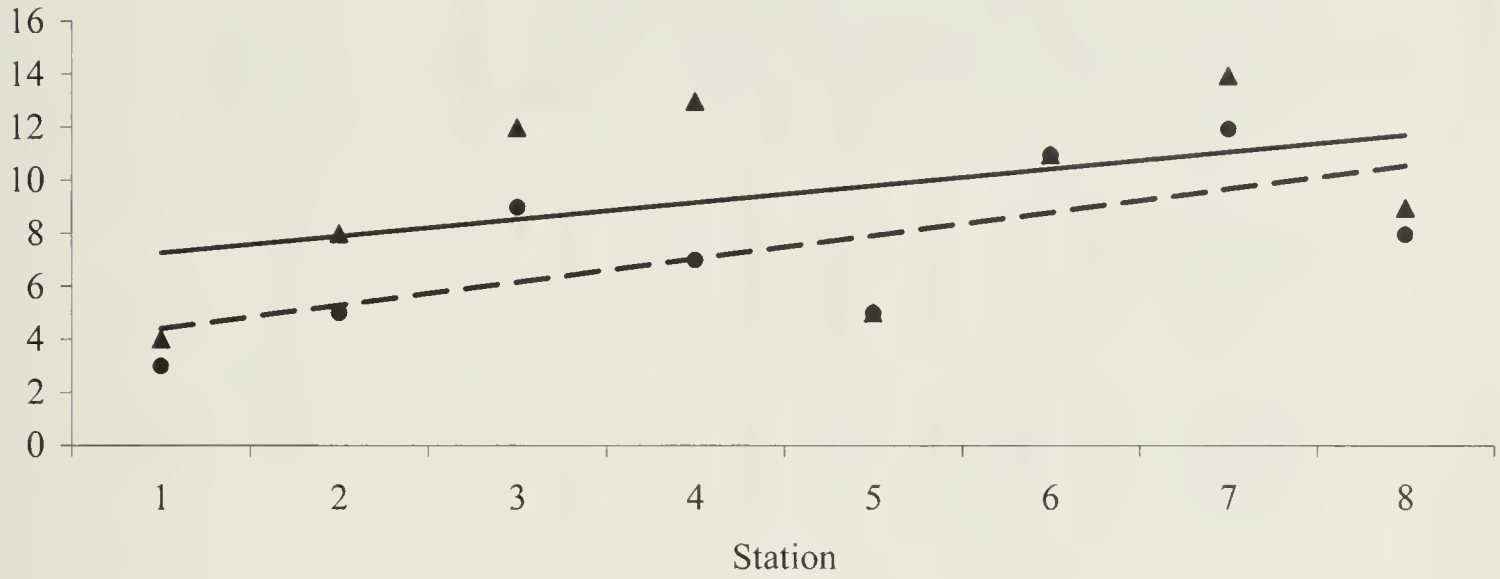
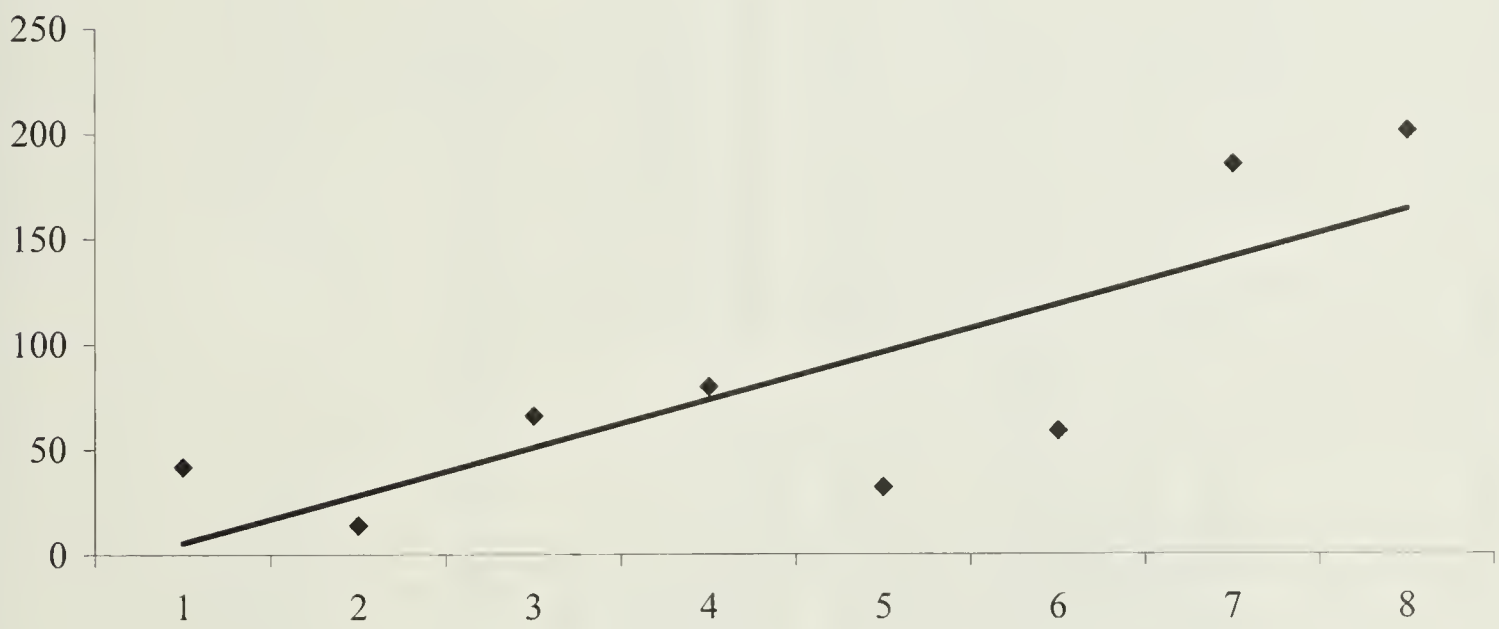


Figure 2. (a) Freshwater mussel extant species richness ($r^2 = 0.48$, $P = 0.06$) (circles with dashed line) and historic species richness ($r^2 = 0.18$, $P = 0.29$) (triangles with solid line) and (b) abundance ($r^2 = 0.63$, $P = 0.02$) versus stations arranged from upstream to downstream Kyte River (see Appendix 1 for station localities).

(a)



(b)



Appendix 1. Station localities from the 2004 freshwater mussel survey of Kyte River in Ogle County, Illinois. All stations were sampled for four person-hours.

Station	General Location	Location	T	R	Sec 1/4	Latitude	Longitude	Date	Comments
1	2 mi SW Rochelle	upstream Brush Grove Road bridge	40N	1E	34 SW	41.8927°	-89.1113°	22 Sep 04	gravel riffles with sand; ditched with grassy banks
2	3.5 mi W Rochelle	downstream & upstream Route 38 bridge	40N	1E	29 NE	41.9139°	-89.1333°	21 Sep 04	gravel riffles with silt/sand; ditched with grassy banks
3	4 mi ENE Rochelle, Skare Park	~400 yds downstream Flagg Road bridge	40N	1E	18 SE	41.9376°	-89.1568°	22 Sep 04	gravel-cobble riffles with sand/silt; woody banks
4	5.5 mi WNW Rochelle	private property	23N	11E	36 NE	41.9452°	-89.1769°	22 Sep 04	gravel-cobble riffles with sand/silt; woody banks
5	1.75 mi S Chana	upstream Chana Road bridge	23N	11E	27 NE	41.9575°	-89.2153°	21 Sep 04	gravel-cobble riffles with sand; woody banks
6	1.25 mi SW Chana	upstream Rocky Hollow Road bridge	23N	11E	21 SW	41.9642°	-89.2441°	21 Sep 04	gravel riffles with silt/sand; sandy-woody banks
7	1.0 mi E Daysville	upstream Honey Creek Road bridge	23N	10E	13 NW	41.9858°	-89.2941°	21 Sep 04	gravel riffles with sand; sandy-woody banks
8	2 mi SSE Oregon	private property	23N	10E	11 SW	41.9912°	-89.3175°	21 Sep 04	gravel riffles with sand; old pasture with woody banks

Appendix 2. Mussel Classification Index (MCI) is used for identifying freshwater mussel assemblages of state-wide significance and has values ranging from Restricted to Unique (Szafoni, 2002). MCI = Species richness factor + Intolerant species factor + Abundance factor + Recruitment factor.

Score	Species richness (# of extant species)	Intolerant species (# of intolerant species)	Factor Abundance (catch-per-unit-effort)	Recruitment (% of live species with recent recruitment)
1	0	0	0	0
2	1-3	-	1-10	-
3	4-6	1	11-30	1-30
4	7-9	-	31-60	31-50
5	10+	2+	61+	51+

MCI

Score	Classification	Definition
16+	Unique	Very high species richness and/or abundance, intolerant species common, and evidence of recruitment. A resource of state-wide significance.
12-15	Highly Valued	High species richness and/or abundance, intolerant species present, and evidence of recent recruitment for at least a third of species present. A resource of state-wide significance.
8-11	Moderate	Species richness and/or abundance typical for stream of given location and order and evidence of recent recruitment for at least one species. May be a resource of local significance or recovering from degradation.
5-7	Limited	Low species richness and/or abundance and no evidence of recent recruitment (all individuals old or large for the species). May be recoverable or recovering with improved conditions.
0-4	Restricted	No live mussels present and only weathered dead, sub-fossil, or no shell material found. Unlikely to be recoverable except through immigration from better sites after improved conditions.

BOOK REVIEW 2005 - #5

Jordan, III, W. R. The Sunflower Forest: Ecological Restoration and the New Communion with Nature. 2003. 256 pages; notes; selected readings; index. University of California Press, Berkeley, California. ISBN: 0-520-23320-4. Hard Cover. US $27.50. Available from the University of California Press, 2120 Berkeley Way, Berkeley, CA 94704-1012.

In his book, The Sunflower Forest, William Jordan III examines ecological restoration and discusses its place in today's society. This book is an outgrowth of an experience of a friend of the author, who became frustrated at a meeting on natural areas when the speaker could not inform the audience of ways to save these important biological remnants. Without answers, the audience left the meeting filled with frustration and despair. After he learned about his friend's experience, Jordan began to assemble his notes and thinking regarding ecological restoration.

It will not take readers long to realize that the author has researched the subject matter extensively and that he has given considerable thought to the development of each chapter. The literature sources used are very diverse, and the author has analyzed and presented them very well. Indeed, it took considerable thought and effort to demonstrate in writing how such diverse disciplines as poetry and critical thinking could be combined to be supportive of the science of ecological restoration.

The author has many years of experience in the science of ecological restoration, but this is not a cookbook filled with useful bits of information to guide aspiring restorationists. Instead, it is a book of serious environmental philosophy that will provide thought provoking moments to all who have a strong interest in the environment. The author draws from his own knowledge and views of authors that represent a wide diversity of disciplines, to illustrate the value and position of ecological restoration in societies throughout the world. The unique combination of writings at the fringes of ecology may cause individuals to shun the book. However, this diversity is one of its greatest strengths and will cause serious-minded restorationists to think through their own actions, perhaps causing them to change their restoration methodologies.

Ecological restorationists sometimes believe that their works are proper and beyond scrutiny, particularly projects involving the removal of invasive exotic species or the monitoring of rare organisms, but others may interpret their works differently. This is why Jordan stresses the necessity of involving other persons and recognizing their diversities of opinions and values. The actions of a single person can affect many others in today's world.

As I continued to read the book, I couldn't help but think of situations or individuals that fit snuggly into Jordan's points. One is his view that some persons regard the land as "colonial" (Chapter 2, Page 28) or simply for the taking. With this philosophy, the land is for profit and only a few selected species of high economic value are managed. Then there are those who regard classic landscapes, such as natural areas, as "sacred places" (Chapter 2, Page 29), and are not willing to do anything with them. Nature knows best and man is merely an interloper who must let the natural processes proceed, regardless of the consequences.

William Jordan proposes a different plan revealed in his concept of the New Communion with Nature. Work with nature to return all restorable systems back to the landscape. Do not focus on just those parts that are of special interest, such as rare plants or animals. All things must be included and man must interact with nature to achieve desired goals. These goals must include those organisms that Jordan regards as socially unacceptable because they are ugly or potentially harmful to humans. The list would also include less spectacular organisms such as fungi or micro-invertebrates.

In addition, Jordan proposes that ecological restoration is not a task just for a small, select group of persons. It should be a community affair. To accomplish this goal, individuals can work with the land where they live, whether in cities, villages, or rural areas. The work may be tiring at times, such as planting or brush cutting, and it can be spiritually invigorating. Jordan believes that this level of involvement causes a person to feel involved and connected to the land. At this stage Jordan's vision for restoration will begin to emerge as the primary means of protecting historic landscapes and our only hope of enlarging sites to sustain species with large habitat requirements.

The author draws extensively from personal experience, and he has assembled a remarkable amount of material from many very distinguished individuals. If you want to gain some new perspectives on ecological restoration, The Sunflower Forest is a book that may help you. However, take time to read it carefully, giving thought to points made by the author. It is not light reading. However, it is reading that may lead the way to solutions to problems facing the troubled ecological systems in societies throughout today's world.

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BOOK REVIEW 2005 - #6

Mohlenbrock, Robert H. Grasses: *Panicum* to *Danthonia*. Second Edition. 2001. xxvi + 455 pages; introduction; dichotomous keys; descriptions; illustrations; distribution maps; appendix; literature cited; index of plant names. Southern Illinois University Press, Carbondale and Edwardsville, Illinois. Hard Cover. Price: US $50.00. ISBN 0-8093-2360-5. Available from Southern Illinois University Press, P.O. Box 3697, Carbondale, IL 62902-3697.

Mohlenbrock, Robert H. Grasses: *Bromus* to *Paspalum*. Second Edition. 2002. xxii + 404 pages; introduction; dichotomous keys; descriptions; illustrations; distribution maps; appendix; literature cited; index of plant names. Southern Illinois University Press, Carbondale and Edwardsville, Illinois. Hard Cover. Price: US $60.00. ISBN 0-8093-2359-1. Available from Southern Illinois University Press, P.O. Box 3697, Carbondale, IL 62902-3697.

When the name Mohlenbrock is mentioned, the usual association for Illinois botanists is his Guide to the Flora of Illinois (Mohlenbrock, 1975, 1986) and his most recent opus, Vascular Flora of Illinois (Mohlenbrock, 2002). Being a relative newcomer to the state, I first heard of his name as the author of a long running, enjoyable and well written series of articles on natural areas in our National Forests. Another series, for which he is also well known, is the Illustrated Flora of Illinois. Its first tome debuted in the early 1970's and additional ones have appeared from time to time since then. In the last several years, several early volumes have been reprinted with additions and nomenclatural changes, hence the occasion for this review.

Since the grasses are a large family, they were divided into two volumes in the first editions and this same division is followed in the second editions. The first volume covers *Bromus* to *Paspalum* and the second covers *Panicum* through *Danthonia*. The arrangement and sequence of genera follow Gould & Shaw's classification (Gould & Shaw, 1983). Each volume has essentially the same format: each has an identical introduction and key to the genera known from Illinois at the time of the publication of the first edition; following are 250 pages or so of descriptions of genera, keys to species, descriptions of species with synonymy, range maps and illustrations; and each volume concludes with an appendix for species added to the state since the first edition. These additions follow the sequence of genera within its respective volume.

It is fortunate that we have the author's identification guide (Vascular Flora of Illinois) with its complete key to the grasses of Illinois. In the two volumes reviewed here, it is not possible to key out a specimen of grass, even using one of the second editions, unless it was included in one of the first editions. Keys to genera and species of the first editions, and reprinted in the second editions, were not updated; instead, keys to the additional 20 or so species are included in their respective appendices. How anyone will get use out of this escapes me. Maybe I am missing something. What I would suggest (and this is how I use the second editions myself, as well as in my taxonomy classes) is to key out grasses using the key in Mohlenbrock's Vascular Flora of Illinois, then look up the descriptions and illustrations in one of the two volumes of the second editions of his grass flora. Another difficulty appears – since there is no combined index for both volumes, the user

must look in the index of each volume to find out, for example, that *Digitaria* is on page 280 in volume number, err, the one that has *Bromus* to *Paspalum* (the one that was printed first in the first edition but second in the second edition). This seems like a long way around, even to get to the excellent illustrations, which will help clinch an identification.

In general, Mohlenbrock's revised grass flora volumes follow current taxonomic thought regarding the Poaceae. For example, *Dichanthelium* is distinguished from *Panicum* (*sensu stricto*), which follows current usage, as exemplified in the Volume 25 of the Flora of North America (FNA: Barkworth, Capels, Long & Piep, 2003). Mohlenbrock provides a number of new taxonomic combinations for some of the infraspecific taxa of *Dichanthelium* in Illinois.

I noted a divergence from FNA in the genus *Bothriochloa* (a relative of *Andropogon*). Mohlenbrock reports *B. sacharoides* (Sw.) Rydb. from several counties in the southern part of the state. However, Barkworth, Capels, Long & Piep (2003) inform us that the name *B. sacharoides* pertains to a Neotropical species with pilose leaves. Our Illinois plants are glabrous and should be treated as *B. laguroides* (DC.) Herter.

In summary, the second editions of Mohlenbrock's important manuals of Illinois grasses contain a wealth of useful information, but because of the separation into two volumes, with two appendices, and the lack of a consolidated index, the information will be difficult to utilize, even for those who are fairly familiar with taxonomy and grasses. For beginners it may be a daunting task. This is a profound irony in The Tall Grass Prairie State.

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Reviewer: Gordon C. Tucker, Associate Professor and Curator of the Stover-Ebinger Herbarium, Department of Biological Sciences, Eastern Illinois University, Charleston, IL 61920-3099.

2005 Annual Meeting
Student Awards

Zoology Division – Paper Presentation

1st Place

SUE GALLO

University of Illinois – Urbana-Champaign

Nest Site Selection and Material Contaminant Transfer in
Tree Swallows Nesting in Calumet

2nd Place

ROBERTA K. NEWBURY

Eastern Illinois University

Home Range, Seasonal Habitat Use, and Fractal Dimension of
Movement Pathways in the Raccoon (*Procyon lotor*):
A Quantitative Analysis of Ana Optimal Foraging Strategy in a Common Mesopredator

Zoology Division – Poster Presentation

1st Place

SARAH BARROW

Southern Illinois University – Edwardsville

Morphological Variation in the New Zealand Mud Snail
(*Potamopyrgus antipodarum*)

2nd Place

JASON EDWARD WILLAND

Western Illinois University

Diel Activity of Ground Beetles (Coleoptera: Carabidae) in a
Coal-Mine Remnant and Soybean Fields in West-Central Illinois

Annual Meeting
April 21 & 22, 2006

UNIVERSITY OF ILLINOIS-CHICAGO
AND
THE FIELD MUSEUM

Keynote Address: Professor Robert D. Martin
Provost, Academic Affairs

Hobbits on Flores: New Hominid Species or Modern Microcephalic?

Professor Robert Martin is a scientist of international reputation, recognized as a leader in both primate biology and the origin of humans. He wrote the widely acclaimed *Primate Origins and Evolution*, a standard textbook in biological anthropology, and *Primate Evolution: A Synthetic Approach* projected for release in September, 2006. Dr. Martin has authored more than 240 scientific publications; has received numerous awards and honors, including from the notable Royal Society and the Medical Research Council of the United Kingdom; and is a fellow of the Institute of Biology, the Zoological Society of London, and most recently, the American Association for the Advancement of Science. He has also served with distinction on the editorial boards of both *Science* and *Nature*.

Professor Martin's expertise is in primate biology and evolution, bridging the traditional fields of zoology, paleontology, and anthropology. His talk will center on the recent discovery of fossil hominid remains in the Liang Bau ("cool cave") on the Indonesian island of Flores. Because of their small size and other anatomical features it was identified as a new hominid species, *Homo flores*, nicknamed "Hobbits." It has been suggested that this species occupied Flores between 90,000 to 18,000 years ago. If true, this means that *Homo flores* existed in the same region of Indonesia and at the same time as two other hominid species: *Homo sapiens*, 45,000 years ago to present on Borneo, and *Homo erectus*, 145,000 to 25,000 years ago on Java. Dr. Martin will discuss his views about the discovery of *Homo flores*.

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